



Culture in Engineering Education CDIO framing intercultural competences

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Conference Proceedings

7th International CDIO Conference

Technical University of Denmark, 20th – 22nd June 2011

This year the CDIO conference returned to Scandinavia, where the second conference was held at Linköping University, Sweden in 2006. The CDIO conferences provide a forum for CDIO collaborators and prospective members to exchange ideas and experiences, follow CDIO developments and progress, and help refine and define the CDIO initiative, its standards and syllabus. The conference took place on DTU's spacious and leafy campus in Lyngby, 12 km north of Copenhagen. Copenhagen is Denmark's capital and largest city, with a population of over a million. It is also one of the world's most environmentally friendly cities, with 36% of its citizens cycling to and from work – a combined distance of 1.2 million km daily! Copenhagen has no less than 10 Michelin-star restaurants (the most of any city in Scandinavia) and is home to the restaurant Noma, currently rated the best in the world.

All extended abstracts were reviewed by at least three members of the Technical Program Committee, and as in the two previous conferences in Montréal (2010) and Singapore (2009) authors were given the option of having their full paper undergo a peer review process. Over 60 of the 155 accepted submissions chose to do so this year. As an additional feature of this year's conference selected papers were forwarded for publication in special issues of the journals *European Journal of Engineering Education (EJEE)*, *Advances in Engineering Education (AEE)* and *International Journal of Quality Assurance in Engineering and Technology Education (IJQAETE)*.

Accepted papers were presented in one of three formats: a 20-minute oral presentation, a poster, or a freestyle session, where the author had free rein to run the session anyway she or he felt appropriate. Eight contributions were given one hour for this purpose – and made for some exciting, interactive, “out of the box” experiences. As in Montréal last year we repeated the successful poster teaser session where authors had a minute to convince you why you should visit their poster. We stress that all contributions appearing here in the proceedings had equal stature at the conference, regardless of the format of presentation. The proceedings also contain an updated version of the CDIO Syllabus “v2.0”

We would like to recognize the many contributions required to organize a conference of this size: The authors who submitted work, without which we could not have had a conference and whose work appears here in the proceedings; the Technical Program Committee; the many reviewers that were needed to handle the volume of submissions we received; the International Advisory Committee for advice; the financial support of DTU, IBM, Grundfos, Lego, Novozymes and Velux; the Local Organizing Committee who attended to the myriad practical details of arranging a conference and finally the conference participants who made the conference such a success.

Martin E. Vigild, Conference Chair

Ron J. Hugo, Technical Program Committee Chair

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The CDIO Syllabus v2.0

An Updated Statement of Goals for Engineering Education

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ABSTRACT

Modern engineering education programs seek to impart to the students a broad base of knowledge, skills, and attitudes necessary to become successful young engineers. This array of abilities is represented in the CDIO Syllabus, an attempt to create a rational, complete, consistent, and generalizable set of goals for undergraduate engineering education. This paper examines the content and structure of the Syllabus, as well as the roles played by the Syllabus in the design and operation of educational programs.

The paper begins by examining the content and structure of the Syllabus, and then contrasts the Syllabus with other important taxonomies of educational outcomes. The CDIO Syllabus is first compared with the UNESCO Four Pillars of Learning, with which it is aligned at a high level. The Syllabus is then compared with national accreditation and evaluation standards of several nations. The finding is that the CDIO Syllabus is consistent and more detailed and comprehensive than any of the individual standards.

Based on these comparisons, as well as other input received over the last decade since the Syllabus was originally written in 2001, a revised and updated Syllabus is presented, in part to add missing skills and in part to clarify nomenclature and make the Syllabus more explicit and more consistent with national standards. The result is called the *CDIO Syllabus version 2.0*.

In modern society, engineers are increasingly expected to move to positions of leadership, and often take on an additional role as an entrepreneur. This paper also explores the degree to which the CDIO Syllabus already covers these topics, and the optional extension to the CDIO Syllabus that more adequately covers these two important roles of engineers.

KEYWORDS

CDIO Syllabus, knowledge taxonomies, ABET, CEAB, CDIO Standard 2, engineering leadership, entrepreneurship

INTRODUCTION

In contemporary undergraduate engineering education, there is a seemingly irreconcilable tension between two growing needs. On one hand, there is the ever-increasing body of technical knowledge that graduating students must command. On the other hand, there is a growing recognition that young engineers must possess a wide array of personal, interpersonal, and system building knowledge and skills that will allow them to function in real engineering teams and to produce real products and systems, meeting enterprise and societal needs.

Over the last decade, there has evolved a broad sense that there is a need to create a new vision and concept for undergraduate education. One approach to this, recognizable to engineering faculty, is to engage this problem by applying an *engineering problem solving paradigm*. This entailed first developing a comprehensive understanding of the skills needed by the contemporary engineer, and then designing and education to meet these requirements. Cast in just slightly different language, educators would begin with the development of educational objectives and learning outcomes, and then design aligned curriculum and assessment. In either framing of the problem, an early step is the development of comprehensive goals and outcomes.

Since 2000, we have been engaged in an organized international educational initiative centered on the CDIO approach, which is structured around 12 principles of effective practice [1]. The first and organizing principle is that the conceiving-designing-implementing-operating of products, processes and systems should be the authentic context of engineering education. [2] A learning context is the set of cultural surroundings and environments that contribute to understanding, and in which knowledge and skills are learned. The CDIO approach holds that the product, process, or system lifecycle (conceiving-designing-implementing-operating), should be the *context*, but not the *content*, of engineering education. The setting of the education, the skills we teach, and the attitudes we convey should all indicate that conceiving-designing-implementing-operating is the authentic role of engineers in their service to society.

A second principle of effective practice of the CDIO approach is that a program should set *“Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders.”* [1] In order to serve as a reference document for this process, the framework document entitled *CDIO Syllabus – A Statement of Goals for Undergraduate Engineering Education* was published in 2001. [3] The *CDIO Syllabus* was developed through discussions with focus groups comprised of various stakeholders, and by reference to other documentation of the time. As shown in Table 1, the CDIO Syllabus classified learning outcomes into four high-level categories: technical knowledge, personal and professional attributes, interpersonal skills, and the skills specific to the engineering profession. The content of each section was expanded in the CDIO Syllabus to a second level (also shown in Table 1), to a third level (see Appendix A), and to a fourth level (see Appendix B). This detailed version of the Syllabus was explicitly correlated with key documents listing engineering education requirements and desired attributes. As a result of this development process, the CDIO Syllabus emerged in 2001 as what we will now call the *CDIO Syllabus version 1.0*.

CDIO Syllabus v1.0 has proven to be a useful reference in over 100 programs worldwide for setting program goals, planning curricula, and evaluating student learning. It has been translated into Swedish, French, Spanish, Vietnamese and Chinese. Of course, the Syllabus is just a reference document, and it is not prescriptive. If programs feel that the Syllabus is not appropriate for their programs, or needs to be expanded, they can modify it in any way desirable to them.

The general objective of the CDIO Syllabus is to summarize formally a set of knowledge, skills and attitudes that alumni, industry and academia desire in a future generation of young engineers. The Syllabus can be used to define expected outcomes in terms of learning objectives of the personal, interpersonal and system building skills necessary for modern engineering practice. Further, the Syllabus can be used to design new educational initiatives, and it can be employed as the basis for a rigorous outcomes-based assessment process, such as that required by the Accreditation Board for Engineering Technology (ABET), and increasingly by other international accreditation processes as well.

The required skills of engineering are best defined through the examination of the practice of engineering for which we prepare our students. In fact, from its conception as a profession until the middle of the 20th century, engineering education was based on practice. With the advent, in the 1950s, of the engineering science-based approach to engineering education, the education of engineers became more distant from the practice of engineering. Engineering science became the dominant culture of engineering schools. Many universities are now moving to a new synthesis of engineering science and authentic practice.

Over the last 30 years, industry in the United States and elsewhere has made a concerted effort to signal their needs and support this transition. Yet, statements of high-level goals, written in part by those outside the academic community, have not made the kind of fundamental impact their authors desired. We examined this issue, and decided there were two root causes for this lack of convergence between engineering education and practice: an absence of rationale and an absence of detail.

Our approach was to reformulate the underlying need to make the rationale apparent. A statement of the underlying need for engineering education is that:

*Graduating engineers should be able to
conceive-design-implement-operate
complex value-added engineering systems
in a modern team-based environment.*

If we accept this conceive-design-implement-operate premise as the *context* of engineering education, we can then rationally derive more detailed goals for the education. The second barrier is the fact that the “lists” of desired attributes, as written, lack sufficient detail and specificity to be widely understood or implemented. Therefore, we composed the CDIO Syllabus to provide the necessary level of detail.

The specific objective of the CDIO Syllabus is to create a clear, complete, consistent, and generalizable set of goals for undergraduate engineering education, in sufficient detail that they can be understood and implemented by engineering faculty. These goals would form the basis for educational and learning outcomes, the design of curricula, as well as the basis for a comprehensive system of student learning assessment. In

addition, they would form the basis for effective communication, benchmarking, inter-university sharing, and international correspondence.

Our goal was to create a taxonomy of engineering learning that is rationalized against the norms of contemporary engineering practice, comprehensive of all known other sources, and peer-reviewed by experts in the field. Further, we sought to develop a list that is prioritized, appropriate to university education, and in a form that can be expressed as learning objectives.

The objective of this paper is to review the CDIO Syllabus, ten years after its drafting, for its applicability and continued relevance. We have introduced some minor changes in the document to increase its contemporary relevance and broaden its coverage, and call this revised document the CDIO Syllabus v2.0. The modifications to the first and second level of the Syllabus are modest, as show in Table 2. The paper first reviews the high-level content and structure of the Syllabus. A discussion is then presented of use of the Syllabus in aligning curriculum, teaching and learning, and assessment. Then the historical development and recent updating of the more detailed Syllabus will be presented, culminating in the complete version 2.0 of the document. Finally, a proposed extension of the Syllabus to include entrepreneurship and leadership is discussed.

Table 1. CDIO Syllabus v1.0 at the Second Level of Detail

<p>1 TECHNICAL KNOWLEDGE AND REASONING</p> <p>1.1 KNOWLEDGE OF UNDERLYING SCIENCE</p> <p>1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE</p> <p>1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE</p> <p>2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES</p> <p>2.1 ENGINEERING REASONING AND PROBLEM SOLVING</p> <p>2.2 EXPERIMENTATION AND KNOWLEDGE DISCOVERY</p> <p>2.3 SYSTEM THINKING</p> <p>2.4 PERSONAL SKILLS AND ATTITUDES</p> <p>2.5 PROFESSIONAL SKILLS AND ATTITUDES</p>	<p>3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION</p> <p>3.1 MULTI-DISCIPLINARY TEAMWORK</p> <p>3.2 COMMUNICATIONS</p> <p>3.3 COMMUNICATIONS IN FOREIGN LANGUAGES</p> <p>4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT</p> <p>4.1 EXTERNAL AND SOCIETAL CONTEXT</p> <p>4.2 ENTERPRISE AND BUSINESS CONTEXT</p> <p>4.3 CONCEIVING AND ENGINEERING SYSTEMS</p> <p>4.4 DESIGNING</p> <p>4.5 IMPLEMENTING</p> <p>4.6 OPERATING</p>
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Table 2. CDIO Syllabus v2.0 at the Second Level of Detail
(Underlined Text is Updated from v1.0)

<p>1 DISCIPLINARY KNOWLEDGE AND REASONING</p> <p>1.1 KNOWLEDGE OF UNDERLYING <u>MATHEMATICS AND SCIENCE</u></p> <p>1.2 CORE FUNDAMENTAL KNOWLEDGE OF ENGINEERING</p> <p>1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, <u>METHODS AND TOOLS</u></p> <p>2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES</p> <p>2.1 <u>ANALYTICAL REASONING AND PROBLEM SOLVING</u></p> <p>2.2 EXPERIMENTATION, <u>INVESTIGATION AND KNOWLEDGE DISCOVERY</u></p> <p>2.3 SYSTEM THINKING</p> <p>2.4 <u>ATTITUDES, THOUGH AND LEARNING</u></p> <p>2.5 <u>ETHICS, EQUITY AND OTHER RESPONSIBILITIES</u></p>	<p>3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION</p> <p>3.1 TEAMWORK</p> <p>3.2 COMMUNICATIONS</p> <p>3.3 COMMUNICATIONS IN FOREIGN LANGUAGES</p> <p>4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT</p> <p>4.1 EXTERNAL, SOCIETAL AND <u>ENVIRONMENTAL CONTEXT</u></p> <p>4.2 ENTERPRISE AND BUSINESS CONTEXT</p> <p>4.3 CONCEIVING, <u>SYSTEMS ENGINEERING AND MANAGEMENT</u></p> <p>4.4 DESIGNING</p> <p>4.5 IMPLEMENTING</p> <p>4.6 OPERATING</p>
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FIRST- AND SECOND-LEVEL CONTENT OF THE CDIO SYLLABUS

First-Level Structure

In this section, we present the high-level content and structure of the CDIO Syllabus. The departure point for the derivation of the CDIO Syllabus' content is the simple statement that *engineers engineer*; that is, they build systems and products for the betterment of humanity. To enter the contemporary profession of engineering, students must be able to perform the essential function of an engineer which, as we have stated is that

*Graduating engineers should be able to:
conceive-design-implement-operate
complex value-added engineering systems
in a modern team-based environment.*

Stated another way, graduating engineers should appreciate the engineering *process*, be able to contribute to the development of engineering *products*, and do so while working in engineering *organizations*. Implicit is the additional expectation that engineering graduates should develop as whole, mature, thoughtful individuals.

These high-level expectations map directly to the first- or highest-level organization of the CDIO Syllabus. (see Table 2) Examining the mapping of the first level Syllabus items to these four expectations, we can see that a mature individual interested in technical endeavors possesses a set of *Personal and Professional Skills and Attributes*, which are central to the practice. In order to develop complex value-added engineering systems, students must have mastered the fundamentals of the appropriate *Disciplinary Knowledge and Reasoning*. To work in a modern team-based environment, students must have developed the *Interpersonal Skills* of teamwork and communications. Finally, to create and operate products and systems, a student must understand something of

Conceiving, Designing, Implementing, and Operating Systems in the Enterprise, Societal and Environmental Context. The four-section organization of the Syllabus reflects disciplinary knowledge, how to think, how to work with others, and how to engineer.

The first section, *Disciplinary Knowledge and Reasoning*, is program specific, that is, it outlines major disciplinary concepts of a specific engineering domain. Sections 2, 3, and 4 are more generic and applicable to virtually any engineering program. One could argue that this structure of Knowledge, Thinking and Acting, Working with Others, and Working Professionally is a taxonomy that can be applied to any field of study which prepares students for a profession. In fact, the CDIO Syllabus has been applied to other professional areas (e.g., business management) largely by customizing Sections 1 and 4, but leaving Sections 2 and 3 largely unchanged.

Second-Level Structure

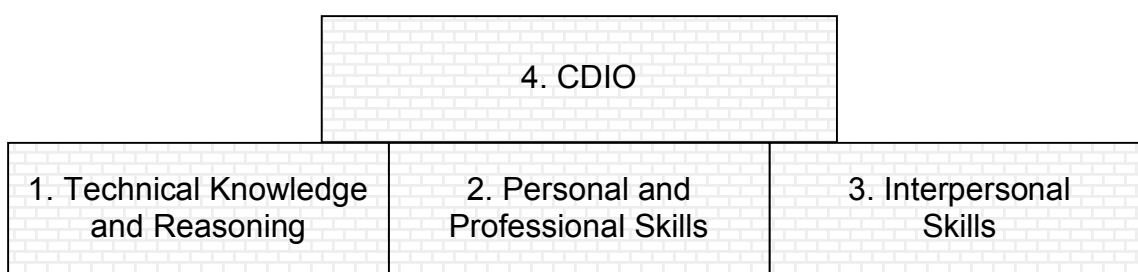


Figure 1: Building blocks of knowledge, skills, and attitudes necessary to Conceive, Design, Implement, and Operate Systems in the Enterprise, Societal and Environmental Context (CDIO).

The second level of the Syllabus consists of 17 sections, assigned to the four sections shown in Figure 1. These are roughly at the level of detail of national standards and accreditation criteria. Section 1 of CDIO Syllabus v2.0 is now called *Disciplinary Knowledge and Reasoning*. Modern engineering professions often rely on a necessary core Knowledge of Underlying Mathematics and Sciences (1.1). A body of Core Engineering Fundamental Knowledge (1.2) builds on that science core, and a set of Advanced Engineering Fundamental Knowledge, Methods and Tools (1.3) moves students towards the skills necessary to begin a professional career. This section of the CDIO Syllabus is, in fact, a placeholder for the more detailed description of the disciplinary fundamentals necessary for any particular engineering education. Section 1 details will vary in content from field to field.

In the remainder of the Syllabus, we have endeavored to include the knowledge, skills and attitudes that all engineering graduates might require. Section 2 begins with the three modes of thought most practiced professionally by engineers: Analytical Reasoning and Problem Solving (2.1), Experimentation, Investigation and Knowledge Discovery (2.2) and System Thinking (2.3). The detailed topical content of these sections at a third level is shown in Appendix A, and a fourth or implementable level is given in Appendix B. There is parallelism in these three sections (2.1 - 2.3). Each starts with a subsection which is essentially “formulating the issue,” moves through the particulars of that mode of thought, and ends with a section which is essentially “resolving the issue.”

Those personal values and attitudes that are used primarily in a professional context and that reflect on responsibilities are called Ethics, Equity and Other Responsibilities (2.5).

These include professional ethics, integrity and social responsibility, professional behavior, visioning for career and life, currency in engineering, equity and diversity and trust and loyalty. While these values and attitudes are applicable to engineering, there is nothing in this section that is conceptually particular to engineering. The subset of personal skills that are not primarily associated with responsibilities, are called Attitudes, Thought and Learning (2.4). These include the general character traits of initiative and perseverance, the more generic modes of thought of creative and critical thinking, and the skills of self-awareness and metacognition, curiosity and lifelong learning and educating, and time management.

Section 3 *Interpersonal Skills* is a distinct subset of the general class of personal skills, focused on interaction with others. They are divided into three overlapping sets called Teamwork (3.1) Communications (3.2), and Communications in Foreign Languages (3.3). Teamwork comprises forming, operating, growing and leading a team, as well as skills specific to technical and multidisciplinary teamwork. Communications comprises the skills necessary for formal communication: devising a communications strategy and structure; and those necessary to use the four common media -- written, oral, graphic and electronic. In addition, there is a set of informal communications and relational skills: inquiry and effective listening, negotiation, advocacy, and networking. Command of a foreign language is an important part of engineering in a globalized society. Because of its importance, English is called out specifically. Languages of regional commerce and industry are also important, for example, speaking both Spanish and Portuguese in South America. Command of additional languages is considered beneficial.

Section 4 *Conceiving, Designing, Implementing, and Operating Systems in the Enterprise, Societal and Environmental Context* presents a view of how product or system development moves through four metaphases, Conceiving (4.3), Designing (4.4), Implementing (4.5), and Operating (4.6). The chosen terms are descriptive of hardware, software and process industries. Conceiving runs from market or opportunity identification through high-level or conceptual design, and includes system engineering and development project management. Designing includes aspects of design process, as well as disciplinary, multidisciplinary, and multi-objective design. Implementing includes hardware and software processes, test and verification, as well as design and management of the implementation process. Operating covers a wide range of issues from designing and managing operations, through supporting product lifecycle and improvement, to end-of-life planning.

Products and systems are created and operated within an Enterprise and Business Context (4.2), and engineers must understand these sufficiently to operate effectively. The skills necessary to do this include recognizing the culture and strategy of an enterprise, and understanding how to act in an entrepreneurial way within an enterprise of any type or size. In addition, working effectively in international organizations, understanding new technology development and engineering project finance are skills which engineers will likely employ. Likewise, enterprises exist within a larger External, Societal and Environmental Context (4.1), an understanding of which includes such issues as the relationship between society and engineering, and requires a knowledge of the broader historical, cultural, contemporary and global context. Increasingly, understanding environmental context, and planning for sustainable development are necessary elements of context.

Comparison with the UNESCO and Other High-Level Frameworks

At its high-level organization, we have tried to organize the CDIO Syllabus in a rational manner. (see Table 2) The first level of Syllabus organization reflects an engineer who is a well-developed individual (Section 2), engaged in a process (Section 4), which is embedded in an organization (Section 3), with the intent of building products (Section 1). The 17 topics at the second level reflect much of the modern practice and scholarship on learning and the profession of engineering.

One of the most important aspects of the CDIO Syllabus is this choice of internal organization. A template for learning outcomes can be organized in many ways. For example, the 11 ABET accreditation criteria (criteria 3a – 3k) are not subdivided into categories at all. [4] The 2008 European EQF characteristics are categorized as Knowledge, Skills and Competences. [5] The 2008 EUR-ACE accreditation criteria are subdivided into Knowledge and Understanding, Engineering Analysis, Engineering Design, Investigations, Engineering Practice, and Transferable Skills.[6] The structure of domains of knowledge and skills (knowledge, personal skills, interpersonal skills and system building) was chosen as the organizing principle of the CDIO Syllabus.

An independent validation of this choice is the universal educational taxonomy developed by UNESCO [7]. They have proposed that all education should be organized around four fundamental types of learning:

- Learning to Know, that is, acquiring the instruments of understanding
- Learning to Do, so as to be able to act creatively on one's environment
- Learning to Live Together, so as to co-operate with other people
- Learning to Be, an essential progression that proceeds from the previous three

The organization of the CDIO Syllabus can be described as an adaptation of the UNESCO framework to the context of engineering education. At the first level, the CDIO Syllabus is divided into four categories:

1. *Technical Knowledge and Reasoning (or UNESCO Learning to Know)*
Section 1 of the CDIO Syllabus defines the mathematical, scientific and technical knowledge that an engineering graduate should have developed.
2. *Personal and Professional Skills and Attributes (or UNESCO Learning to Be)*
Section 2 of the Syllabus deals with individual skills, including problem solving, ability to think creatively, critically, and systemically, and professional ethics.
3. *Interpersonal Skills: Teamwork and Communication (or UNESCO Learning to Live Together)*
Section 3 of the Syllabus lists skills that are needed in order to be able to work in groups and communicate effectively.
4. *Conceiving, Designing, Implementing and Operating Systems in the Enterprise, Societal and Environmental Context (or UNESCO Learning to Do)*
Finally, Section 4 of the CDIO Syllabus is about what engineers do, that is, conceive-design-implement-operate products, processes and systems within an enterprise, societal, and environmental context.

Although the UNESCO framework precedes the first draft of the CDIO Syllabus by several years, the original drafters of the Syllabus did not know of its existence. Thus, UNESCO and CDIO independently arrived at the same fundamental structure of four pillars of education.

Comparison with Engineering Professional Career Tracks

Another indicator of the rational structure of the Syllabus is the degree to which it maps to the needs of various career tracks that engineers follow as professionals. The Syllabus implicitly identifies a generic set of skills needed by all engineers, as well as more specific sets needed by different career tracks. The generic skills applicable to all tracks include: Analytical Reasoning and Problem Solving (2.1), System Thinking (2.3), Attitudes, Thought and Learning (2.4), Ethics, Equity and Responsibility (2.5), Teamwork (3.1), Communications (3.2), Communications in Foreign Languages (3.3) and External and Societal Context (4.1).

There are at least five different professional tracks that engineers follow, according to their individual talents and interests. The tracks and supporting sections of the Syllabus are:

1. The Researcher — Experimentation, Investigation and Knowledge Discovery (2.2)
2. The System Designer/Engineer — Conceiving, System Engineering and Management (4.3)
3. The Device Designer/Developer — Designing (4.4), Implementing (4.5)
4. The Product Support Engineer/Operator — Operating (4.6)
5. The Entrepreneurial Engineer/Manager — Enterprise and Business Context (4.2)

Of course, no graduating engineer will be expert in all of these potential tracks, and in fact may not be expert in any. However, the paradigm of modern engineering practice is that an individual's role will change and evolve. The graduating engineer must be able to interact in an informed way with individuals in each of these tracks, and must be educated as a generalist, prepared to follow a career that leads to any one or combination of these tracks.

It is important to note that the CDIO Syllabus exists at four levels of detail as shown in Appendix B. This decomposition is necessary to transition from the high-level goals (e.g., all engineers should be able to communicate) to the level of teachable and assessable skills (e.g., a topic in attribute 3.2.1, "analyze the audience"). This level of detail has many benefits for engineering faculty members, who in many cases are not experts in some of these topics. The detail allows instructors to gain insight into content and objectives, contemplate the deployment of these skills into a curriculum, and prepare lesson and assessment plans.

We have attempted to explain how the Syllabus forms a rational and generalizable basis for the goals of engineering education. Before discussing the Syllabus content in more detail, we briefly describe the use of the Syllabus in planning, executing and evaluating an educational program.

THE ROLE OF THE CDIO SYLLABUS IN EDUCATION

In the past ten years, the CDIO Syllabus has played a key role in the design of curriculum, teaching, and assessment in engineering education. As a formal statement of the intended learning outcomes of an engineering program, the Syllabus was able to

- Capture the expressed needs of program stakeholders
- Highlight the overall goals of an engineering program
- Provide a framework for benchmarking outcomes
- Serve as a template for writing program objectives and outcomes

- Provide a guide for the design of curriculum
- Suggest appropriate teaching and learning methods
- Provide the targets for student learning assessment
- Serve as a framework for overall program evaluation, and
- Communicate with faculty, students, and other stakeholders about the direction and purpose of a renewed engineering education that is centered on students and focused on outcomes.

In the curriculum and instructional design process, the CDIO Syllabus was adapted to diverse engineering programs in order to ensure that intended learning outcomes were aligned with institutional mission and vision, program objectives, and institutional and program values. (see Figure 2) This sometimes meant that a program omitted a few of the personal, interpersonal, and product, process, and system building skills found in the CDIO Syllabus, or added a few to highlight specific values of its institution.

The list of intended learning outcomes, adapted from the CDIO Syllabus, served as the basis for instructional decisions about curriculum, teaching and learning methods, and the assessment of student learning. In the curriculum design process at the program level, intended learning outcomes were detailed, sequenced from basic to complex, and mapped to appropriate levels and courses in the overall curriculum. For example, an intended learning outcome related to oral and written communication would be further defined into enabling steps and learning activities that would be integrated into courses at all levels of the curriculum so that by graduation, students would be able to demonstrate their competence in oral and written communication.

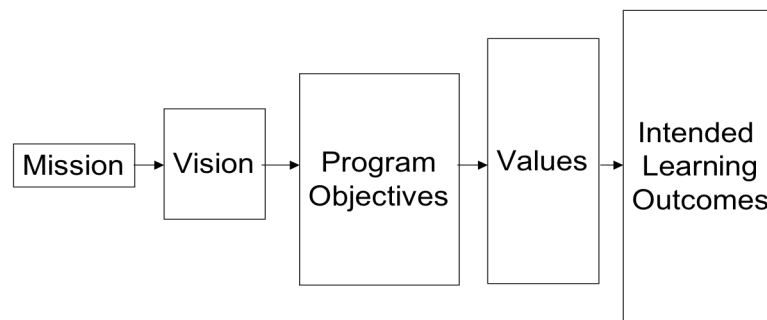


Figure 2. Alignment of intended learning outcomes with program mission

In the instructional design process at the course level, intended learning outcomes were used to guide decisions about appropriate teaching, learning, and assessment methods. The appropriateness of teaching and assessment methods depends on the nature and level of the learning outcomes. Using the same example of communication, appropriate teaching and assessment methods would be those that would allow students to practice their skills, get feedback on their performance, and in an assessment situation, demonstrate their achievements. Biggs refers to this purposeful relationship between the intended learning outcomes, teaching and learning activities, and assessment of student learning as *constructive alignment*. [8] (see Figure 3) Wiggins and McTighe refer to the outcomes, teaching and learning, and assessment sequence as *backward design*. [9] With or without a specific name, all models of instructional design highlight the centrality of learning outcomes and the importance of the alignment of curriculum, teaching, and

assessment. The CDIO Syllabus was used as a starting point for defining these learning outcomes at the course level.

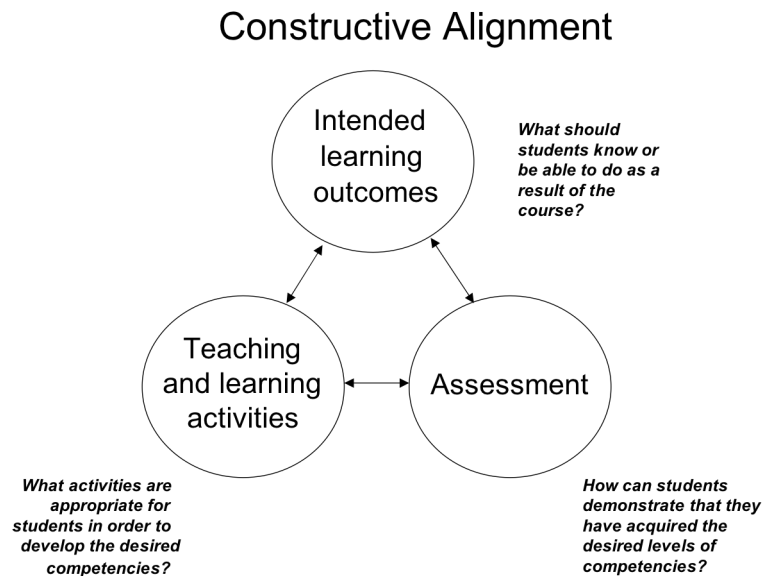


Figure 3. Alignment of intended learning outcomes with teaching and assessment

The CDIO Syllabus was also used in program evaluation and accreditation. For example, engineering programs at four different universities in the United States used the Syllabus as the framework for their self-studies for accreditation by ABET. [4] Using the language of ABET's EC2010, the CDIO Syllabus at the first level addressed ABET *Criterion 2 – Educational Objectives*. The topics of the Syllabus at the second level addressed ABET *Criterion 3 – Educational Outcomes*. Each topic was written as an educational outcome, in much the same language as ABET's required outcomes specified in Criteria 3a through 3k. These program learning outcomes subsequently became the starting point for writing learning outcomes for each course in the engineering curriculum.

ORIGIN AND EVOLUTION OF THE CDIO SYLLABUS

Developing Version 1.0 of the Syllabus

The CDIO Syllabus aims to be complete, consistent, and clear; that is, to describe the knowledge, skills, and attitudes expected of a graduating engineer in sufficient detail that curricula can be planned and implemented, and student learning assessed. While there is general agreement about the high-level view of these expectations among the comprehensive source documents cited [4,5,6,7], they lack the detail necessary to actually plan instruction and assess learning. We first present a brief review of the process used to arrive at the detailed content of the Syllabus a decade ago. The process blended elements of a product development user need study with techniques from educational research. The detailed content was derived through multiple steps, which included a combination of focus group discussions, document research, surveys, workshops and peer reviews.

Focus Groups

The first step in gathering the detailed content of the Syllabus was engaging four focus groups at MIT, including one of faculty, a group of current students, a group of industrial representatives, and a broadly based external review committee. To ensure applicability to all engineering fields, we included individuals with varied engineering backgrounds. The groups were presented with the question, “What, in detail, is the set of knowledge, skills and attitudes that a graduating engineer should possess?”

Document Review

A number of primary source documents were reviewed. The four principal ones were studied in the approximate chronological order of their appearance: the goals of the 1988 MIT Commission on Engineering Undergraduate Education, the ABET EC 2000 accreditation criteria [4], Boeing’s Desired Attributes of an Engineer [10], and the goals of the 1998 MIT Task Force on Student Life and Learning. These four sources were representative of the views of industry, government and academia on the expectations for a university graduate.

Draft Organization and Survey

We organized results of the focus groups, plus the topics extracted from the four principal source documents into a first draft, which contained the first multi-level organization of the content. This preliminary draft needed extensive review and validation. To obtain stakeholder feedback, a survey was conducted among four constituencies: faculty, senior industry leaders, young alumni (average age 25) and older alumni (average age 35). The qualitative comments from the roughly 100 respondents to this survey were incorporated, improving the Syllabus’ organization, clarity and coverage.

Workshops and Faculty Review

The first draft and survey comments were thoroughly reviewed in a faculty workshop at MIT and significantly reworked. This resulted in a second draft of the CDIO Syllabus, which was the first to have the four topics of the first-level organization (disciplinary knowledge, etc.), and contained 16 second-level sections (3 of which are placeholders in Section 1). These first- and second-level topics have been stable, with small changes, since 2000. The only second-level section subsequently added was 3.3 Communications in Foreign Languages. Using the information gathered from the focus groups, documents, surveys and workshops, the third level (Appendix A) and fourth level (Appendix B) of the Syllabus were developed.

Peer Review

The second draft of each of the 13 second-level topics in Sections 2 through 4 of the Syllabus was sent to disciplinary experts for review, that is, communications experts reviewed 3.1, design experts reviewed 4.4, etc. Through the expert reviews, we identified additional comprehensive source documents, as well as detailed references appropriate for each section. The peer reviewers also helped us to make the document more consistent with the organization of knowledge and terminology used by professionals in each of the fields. Combining the results of the peer review, and the check of additional comprehensive and detailed sectional references, we completed the third major draft of the Syllabus.

Collaborator review

In 2000, the CDIO Initiative was just beginning. Up to this point, the Syllabus had been under development at MIT. However, the final drafting of version 1.0 of the Syllabus became one of the first projects of the new collaboration. The Syllabus was reviewed from a European perspective, and, respectively, by mechanical, systems/IT, and transportation engineering faculty from Chalmers University of Technology, Linköping University, and the Royal Institute of Technology (KTH). This review surfaced many details that were specific to the U. S., to MIT, or to aerospace engineering. The outcome was a “translation” of the document into more generic form, with an attempt to find more universal terminology. Section 3.3, Communications in Foreign Languages, was also added at this time.

This multi-step process led to the publication of Version 1.0 of the CDIO Syllabus in 2001 [3].

Revising the Syllabus to Create Version 2.0

Since the CDIO Syllabus was first drafted more than ten years ago, it has been a remarkably stable document, serving programs in all domains of engineering in educational institutions of all types throughout the world. However, there have been pressures to change the Syllabus. These pressures have two primary sources. The first pressure arises from the development of new taxonomies of knowledge that surface new issues or organizations that should be considered. The second pressure comes from questions from users of the Syllabus looking for clarification or for knowledge and skill areas that seem to be missing. We review the correlation of the CDIO Syllabus with other documents, and then summarize the most frequently heard user concerns.

Comparison with ABET

The most common comparison documents for the CDIO Syllabus are those of national accreditation or evaluation bodies, usually produced by governments or professional societies. CDIO programs at different universities worldwide usually need to meet their respective national or accreditation standards, for example, ABET in the United States [4] or the National Agency for Higher Education in Sweden [11]. This need brings the correlation of the CDIO Syllabus with national outcomes requirements into focus. During the development of the first version of the CDIO Syllabus, it was correlated with the outcomes criteria of ABET EC2000. The updated Syllabus has been correlated with ABET EC2010. [4] The most relevant section of ABET EC2010 is Criterion 3 on *Program Outcomes and Assessment*. (Additions to the EC2000 criteria are underlined.)

Engineering programs must demonstrate that their graduates have

- (a) an ability to apply knowledge of mathematics, science, and engineering
- (b) an ability to design and conduct experiments, as well as to analyze and interpret data
- (c) an ability to design a system, component, or process to meet desired needs within realistic constraints, such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- (d) an ability to function on multidisciplinary teams
- (e) an ability to identify, formulate, and solve engineering problems

comparisons, a similar pattern appears: The CDIO Syllabus states outcomes for engineering education that reflect a broader view of the engineering profession, and its greater levels of detail facilitate program and course development. A program whose design is based on the CDIO Syllabus will also satisfy its national requirements for specified program outcomes.

The principal modifications in the CDIO Syllabus that were identified by detailed comparisons with national accreditation and evaluation documents were primarily the clarification of some of the topics so that the correspondence is more explicit. The following changes were made in version 2.0 of the Syllabus: (see Appendix A and Appendix B)

- 1.0 -- Change to *Disciplinary Knowledge and Reasoning* (Swedish Ordinance and EUR-ACE)
- 1.1 -- Add *Mathematics* (ABET)
- 1.3 -- Add *Methods and Tools* (ABET and CEAB)
- 2.1 -- Change to *Analytical Reasoning and Problem Solving* (ABET and CEAB)
- 2.2 -- Add *Investigation* to the title (CEAB)
- 2.5.1 -- Change to *Ethics, Integrity, and Social Responsibility* (ABET and CEAB)
- 2.5.5 -- Add *Equity and Diversity* (CEAB)
- 3.1.5 -- Add *Multidisciplinary Teaming* (ABET and CEAB)
- 3.2.7 -- Add *Inquiry, Listening and Dialogue* (CEAB)
- 4.2.7 -- Add *Engineering Project Finance and Economics* (CEAB and UK-SPEC)
- 4.3.1 -- Add *Understanding Needs* (ABET and CEAB)
- 4.3.3 -- Add *Systems Engineering* (CEAB)
- 4.4.6 -- Modify to indicate *safety* (CEAB)

Modifications Based on User Feedback

Innovation and Invention

In the last decade, the concept of innovation as a role or purpose of engineering has become commonly accepted. However, there are several different understandings of the word *innovation*. The broader one is the development and exploitation of new ideas. A more specific understanding applicable to engineering is that *innovation* is the development and introduction into the market of new goods and services. If one accepts this latter definition, innovation is just the market-oriented view of what the CDIO Syllabus defines in Sections 4.2 through 4.6 – Conceiving, System Engineering and Management, Designing, Implementing, and Operating, within an enterprise. More emphasis may need to be placed on understanding the market and user needs as a basis for developing goals, but otherwise, the skills and knowledge necessary to foster this more specific use of innovation is included in the CDIO Syllabus. *Invention* refers to the development of new technologies that may enable innovations, including their incorporation into products and services that will be delivered. While invention is present in the CDIO Syllabus, it is made explicit only at the fourth level of detail. It was necessary to raise the visibility of this important engineering function.

With respect to innovation and invention, the following modifications to the CDIO Syllabus are incorporated into version 2.0: (see Appendix A and Appendix B)

- 4 -- Add *Innovation* to the title
- 4.2.2 -- Change to *Enterprise Stakeholders, Strategy and Goals*
- 4.2.6 -- Add *New Technology Development and Assessment*
- 4.2.7 -- Add *Engineering Project Finance and Economics*

- 4.3.1 -- Change to *Understanding Needs and Setting Goals*

Sustainability

During the last decade, the importance of sustainable development has become widely recognized. Future engineers need to be able to mitigate the negative environmental consequences of current energy and production systems, and create new ones that are essentially carbon neutral. It follows that engineering education must emphasize sustainability principles. In this context, the CDIO Syllabus, v1.0, had received some criticism, as sustainability is mentioned in only one place, at the fourth level of detail, under 4.4.6. The low visibility has been interpreted as insufficient emphasis on this topic.

However, it could also be argued that CDIO is fundamentally aligned with the ideas of sustainability: Engineers are said to conceive, design, implement and operate complex technical systems with the entire product/process/system lifecycle in mind. Moreover, sustainability is a complex concept. It includes three main dimensions: economic, environmental, and social sustainability, including both subject matter and judgmental aspects, such as, ethics and decision-making [16]. There are many places in the CDIO Syllabus that emphasize the lifecycle perspective, for example, requirements should cover all phases of the lifecycle; analyses should be made of lifecycle values and costs; and product retirement should be planned ahead. With this broader perspective in mind, links between sustainability principles and CDIO Syllabus topics were identified [17]. In essence, we concluded that the CDIO Syllabus does support the development of an engineering education that strongly considers sustainability. Nevertheless, the visibility of the concept of sustainability needed to be strengthened in the CDIO Syllabus, signaling its importance to students, industry, and program and course developers.

Based on these issues of *sustainability*, the following modifications to the CDIO Syllabus are incorporated into version 2.0: (see Appendix A and Appendix B)

- 4 -- Include *Environmental*
- 4.1 -- Include *Environmental*
- 4.1.7 -- Add *Sustainability and the Need for Sustainable Development*
- 4.4.6 -- Make *Design for Sustainability* more explicit
- 4.5.1 -- Change to *Designing a Sustainable Implementation Process*
- 4.6.1 -- Change to *Designing and Optimizing Sustainable and Safe Operations*

Internationalization and Mobility

Engineers increasingly work with international partners at a site, in multinational companies, and with companies, suppliers or markets in different lands. The engineering workforce itself is more mobile, and it is not uncommon for engineers to work in nations other than the one in which they received their training. In order to prepare students for this future, there were several subtle but meaningful changes made to the Syllabus:

- 4.1.6 -- Add *Developing a Global Perspective*
- 4.2.5 -- Add *Working in International Organizations*

The Syllabus already had several sections pertinent to internationalization, including 3.3 Communications in Foreign Languages and reference in 2.5.2 to international norms. The two new topics work in concert with other aspects of the Syllabus to prepare a student for mobility and international efforts.

Other Critiques and Inputs

Over the years, several universities have observed that the CDIO Syllabus does not place sufficient emphasis on the topics of ethics, morality, and social responsibility. For

example, two universities in Chile adapted the CDIO Syllabus to their programs by adding to 2.4 the following (translated from the Spanish): *Commitment to Christian principles; Concern for those in great need; and Concern for the environment*. In response to this criticism, Section 2.5 was renamed as *Ethics, Equity and Other Responsibilities*, and 2.5.5 *Equity and Diversity* and 2.5.6 *Trust and Loyalty* were added.

Others have observed that, while the CDIO Syllabus covers aspects of formal communication well, that is, writing, oral presentations, and graphics, it could be more explicit about informal and interpersonal communications. This led to the inclusion of several new topics in Section 3.2, including:

- 3.2.7 – Add *Inquiry, Listening and Dialog*
- 3.2.8 – Add *Negotiation, Compromise and Conflict Resolution*
- 3.2.9 – Add *Advocacy*
- 3.2.10 – Add *Establishing Diverse Connections and Networking*

Another important critique is based on the work of Johan DeGraeve, which proposes a *Five-E Model* for engineering education. The model, developed at Group T International University College in Leuven, Belgium, describes five “E” terms around which their program of educating *integral engineers* is built. [18] The first three E’s represent the roles engineers play in society.

1. **ENGINEERING** -- making things
Integral engineers create by making use of technology and the underlying sciences. They are familiar with a multidisciplinary approach.
2. **ENTERPRISING** -- getting things done
Integral engineers have vision. On this basis, they define a mission around which they gather others. Through innovation, daring and leadership they effectively get things done.
3. **EDUCATING** -- developing oneself and others
Integral engineers are capable of coaching themselves, others, and teams. Their ideal is the development of each and everyone.
4. **ENVIRONMENTING** -- embracing all elements
Integral engineers are conscious of the influence of technology on the world, and vice versa. This is why they take into account the impact of their actions on ethics, ecology, aesthetics and economics within a globalizing and ever-evolving world.
5. **ENSEMBLING** -- transcending and including
Integral engineers see the coherence of things. By differentiating and integrating, and approaching all things from different angles, they achieve deeper insights and arrive at ever-richer experiences.

Based on a review of this document, the following minor changes were made to the Syllabus in version 2.0:

- 2.4.5 -- Add *Knowledge Integration (Ensembling)*
- 2.4.6 -- *Educating* was added

While helpful in rounding out the Syllabus, these modest changes do not necessarily capture the full scope of DeGraeve’s vision of engineering education.

The net result of this process of comparison with national accreditation and evaluation document, user and other feedback is the revised version 2.0 of the CDIO Syllabus, found in Appendix A and Appendix B.

LEADERSHIP AND ENTREPRENEURSHIP

In modern society, engineers are increasingly expected to move to positions of leadership and to take on additional roles as entrepreneurs. Leadership is not necessarily positional, that is, a leader need not be a boss, manager, director or president. *Leadership* refers to the role of helping to organize effort, create vision, and facilitate the work of others. In the context of engineering, senior engineers are the ones who most often lead. *Entrepreneurship* in this context refers to the specific activity of creating and leading a new enterprise. Many, but not all, new enterprises are built around a product or technology, and involve entrepreneurial engineers. In this section, we explore the degree to which *leadership* and *entrepreneurship* are already included in the CDIO Syllabus v2.0, and the extensions that are necessary to more adequately address these two important roles of engineers.

Engineering leadership and entrepreneurship are not orthogonal to the skills already contained in the CDIO Syllabus. After all, the goal of the CDIO approach is “To educate students who are able to:

- Master a deeper working knowledge of technical fundamentals
- *Lead* in the creation and operation of new products, processes, and systems...” [1]

The knowledge, skills, and attitudes needed in the creation and operation of new products, processes, and systems should, therefore, already be contained in the CDIO Syllabus. In fact, there is a broad overlap, both between leadership and entrepreneurship, and between the two of them and the skills already in the Syllabus. To a certain extent, the three are just different profiles of the same broader set of skills, as suggested in Figure 6. This Venn diagram suggests the organization of the discussion that follows. We have already reviewed the CDIO Syllabus v2.0. Here, we discuss what could be added to expand the topics in the Syllabus beyond the already proposed modifications, to include *Engineering Leadership*. Finally, we examine what other topics are needed to embrace *Entrepreneurship*.

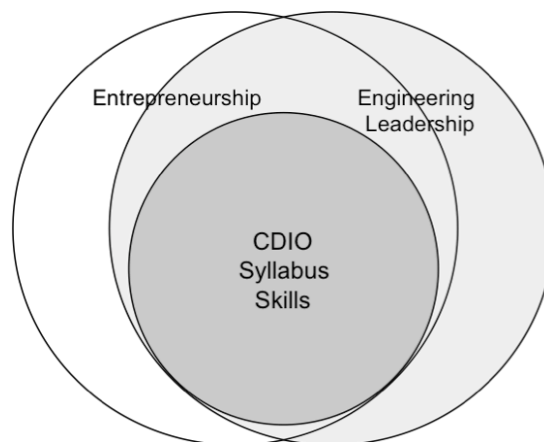


Figure 5. The overlapping relationship between the knowledge, skills and attitudes in the CDIO Syllabus, engineering leadership, and entrepreneurship

We recognize that many programs that use the CDIO Syllabus do not address leadership and entrepreneurship in their programs. For this reason, we have created an extension of the CDIO Syllabus for Leadership and Entrepreneurship, with the additional content discussed below. (see Appendix A and Appendix B)

The Expansion of the CDIO Syllabus to Include Engineering Leadership

Some, if not all, engineers will move, at some point in their careers, to positions of technical or engineering leadership, ranging from being a leader of a small team, to being the technical leader of an entire enterprise. Leadership is explicitly discussed in Section 3.1.4 of the CDIO Syllabus, but this topic discusses the skills needed in leading small groups, and is only a placeholder for the wider set of skills that an engineering leader is required to have. These skills include character traits, such as loyalty and integrity, and abilities, such as the ability to make sense of complex contextual information, to relate and persuade, to create transformational visions, and to deliver on those visions. In this section, we discuss relevant contemporary models of leadership, and propose extensions to the CDIO Syllabus.

Leadership Models

Much has been written over the years about the qualities of a leader. In contemporary scholarship, organizational leadership is closely studied by those in organizational behavior groups, often at schools of business or management. Diverse fields, including business, government, and the military have adopted these organizational models, and customized them to their respective domains. Generic models of leadership, then, can be customized for engineering contexts.

Among the many views of leadership development, the general approaches that may best fit engineering contexts are those that function in environments of change, uncertainty, and the deliberate pursuit of invention. [19] One school of thought that stands out is *Transformational Leadership* because of its emphasis on a driving need to change and to mobilize resources in new ways, requiring new visions of the future. [20] This model resonates with leaders of groups that use applied science and engineering to generate new products that may require redefining markets and business models.

Contingency theory reminds leaders that over time no single approach to leadership will fit all situations, and one must continually assess one's environment to provide appropriate leadership. [21] This approach thus incorporates the importance of providing vision and strong direction in one circumstance, and also recognizes when one might lead best by creating a stable and supportive environment in which others might lead. This view suggests that engineering leadership in a change-driven environment is situational. [22] The complex and specialized nature of engineering requires that leadership be found everywhere. There are instances when one must be able to listen to the technician on the shop floor who might be the first to see the solution to a design-for-production problem. In advancing technical fields, the individuals looking outward from the company at new technologies, and those working in an organization's laboratories, provide a kind of technology leadership. Others who follow markets, and observe novel uses of products that are enhancing or eroding markets, must exert a kind of situational leadership as well. All of these leaders need first to recognize that change is occurring, to make sense of what they are seeing and to communicate effectively with others.

The Four Capabilities Leadership Framework

The *Four Capabilities Leadership Framework*, developed at the Sloan School of Management at MIT, provides a scheme that organizes key leadership concepts as a foundation for engineering leadership education. [23] It begins with four assumptions: that leadership is distributed; that it is personal; that it continues to develop throughout one's career, and thus changes over time; and that each individual invents his/her own framework for how he/she will lead. The central skills are

1. *Sensemaking* -- making sense of the context of the changing world around us, including the use of small experiments to test and gain information
2. *Relating* -- developing trusted relationships with diverse individuals, using inquiry to know how to communicate effectively, and leadership through advocacy, even if one is not a formal leader
3. *Visioning* -- both to create a vision for oneself and to convey that vision to others
4. *Realizing the Vision (Inventing)* -- takes on a more complex meaning for engineers. Engineering leaders, like other leaders, need to invent ways to think through situations, and create ways of organizing their work with others. For engineers, the tasks of organizing work are central to their profession. This organization may involve establishing design teams, designing, setting up production and implementation, establishing who will do testing and by what means, operating, and a host of other activities.

The Bernard M. Gordon – MIT Engineering Leadership Program adapted this generic model of leadership to the context of engineering. Two sets of skills were added to the MIT Sloan Four Capabilities Model. The first set includes issues of leadership that have to do with attitudes and character, for example, initiative, the will to deliver, resourcefulness, integrity, and loyalty. The second set concentrates on a firm foundation of engineering knowledge and skills. The customized leadership model has six central skills:

1. The Attitudes of Leadership - Core Personal Values and Character
2. Relating to Others
3. Making Sense of the Context
4. Creating a Purposeful Vision
5. Realizing the Vision
6. Technical Knowledge and Critical Reasoning

Information about the *Gordon-MIT Engineering Leadership Program* can be found at <http://web.mit.edu/gordonelp>.

Comparing the structure of the *Gordon-MIT Engineering Leadership Program Capabilities of an Engineering Leader* with the CDIO Syllabus reveals a great deal of overlap. Version 2.0 of the Syllabus captures virtually all of the ideas contained in the first three sections of the *Capabilities of an Engineering Leader*, namely:

- **Attitudes of Leadership – Core Personal Values and Character**, including topics in Attitudes, Thought and Learning (2.4), and in Ethics, Equity and Other Responsibilities (2.5)
- **Relating to Others**, including topics in Teamwork (3.1), Communications (3.2) and potentially Communications in Foreign Languages (3.3)
- **Making Sense of Context**, including topics in External, Societal and Environmental Context (4.1), Enterprise and Business Context (4.2) Conceiving, Systems Engineering and Management (4.3) and System Thinking (2.3)

In addition, a new section 4.7 *Leading Engineering Endeavors* has been added to the Extended Syllabus v2.0. This new section defines the remaining topics in *Creating a Purposeful Vision* (4.7.1 to 4.7.4) and *Realizing the Vision* (4.7.5 to 4.7.10). (see Appendix A and Appendix B)

Creating a Purposeful Vision

- 4.7.1 – *Identifying the Issue, Problem or Paradox* (expands 4.3.1)
- 4.7.2 -- *Thinking Creatively and Imagining Possibilities* (expands 2.4.3)
- 4.7.3 -- *Defining the Solution* (expands 4.3.1)
- 4.7.4 -- *Creating New Solution Concepts* (expands 4.3.2 and 4.3.3)

Realizing the Vision

- 4.7.5 -- *Building and Leading an Organization and an Extended Organization* (builds on 4.2.4 and 4.2.5)
- 4.7.6 -- *Planning and Managing a Project to Completion* (builds on 4.3.4)
- 4.7.7 -- *Exercising Project/Solution Judgment and Critical Reasoning* (builds on 2.3.4 and 2.4.4)
- 4.7.8 -- *Innovation* – the conception, design and introduction of new goods and services (the leadership of 4.3 and 4.4)
- 4.7.9 -- *Invention* – the development of new devices, materials or processes that enable new goods and services (expands 4.2.6)
- 4.7.10 -- *Implementation and Operation* – the creation and operation of the goods and services that will deliver value (the leadership of 4.5 and 4.6)

The Expansion of the CDIO Syllabus to Include Entrepreneurship

Successful engineering entrepreneurship consists of engineering, plus engineering leadership, plus specific domain knowledge associated with business formulation and start-ups. As illustrated in Figure 6, we now define the knowledge and skills necessary for *Entrepreneurship*, over and above those described in the baseline CDIO Syllabus, v. 2.0, with the extension for engineering *Leadership*. Again, we examine appropriate models of entrepreneurship on which to base the discussion.

In the view of classical economics, *entrepreneurship* involves the redirection and mobilization of capital and human resources to form a new economic activity. This perspective considers any major innovation in an established firm to be entrepreneurship if it involves a novel economic activity that departs from the firm's prior business model, and accepts the risks of placing substantial investments in new products and creating new markets that did not previously exist. Today, the term *entrepreneurship* generally refers exclusively to starting a new company, while launching a radically new line of business is sometimes called *intrapreneurship*, or more simply *innovation* (as was discussed in a previous section). [24]

Engineering education should prepare students for both forms of entrepreneurship, which are more easily accommodated than intrapreneurship. In many instances, science- and technology-based discovery and invention in established companies may not require business innovation because often they do not require changes in markets. When engineering is a major component of a product that is intended to disrupt existing markets, much more care is needed in the design process, and the engineer needs to understand the trade-offs between product novelty and importance of time to market, product margins and hurdle rates needed to justify company investment, and other business considerations that influence design and implementation strategies. These

issues are well addressed in the product development literature and can be included without difficulty in any engineer's education. In the context of the CDIO Syllabus, these aspects of learning would be largely addressed by the modifications discussed with respect to innovation.

Preparation for entrepreneurship, that is, the start of a new company, involves unique competencies. There are analogues, such as the similarity between recognizing new opportunities enabled by advancing technology, or writing business plans for either a new product line or a new company. However, there is an array of skills that engineers in an established company might never face, such as finding and hiring an entire company of talented professionals willing to accept risk, using equity to motivate innovation, or creating a new company culture where none existed.

In order to capture these additional skills of entrepreneurship, Section 4.8 was added to the Extended Syllabus v2.0. This new section includes the following topics: (see Appendix A and Appendix B)

- 4.8.1 -- *Company Founding, Formulation, Leadership and Organization*
- 4.8.2 -- *Business Plan Development*
- 4.8.3 -- *Company Capitalization and Finances*
- 4.8.4 -- *Innovative Product Marketing*
- 4.8.5 -- *Conceiving Products and Services Around New Technologies*
- 4.8.6 -- *The Innovation System, Networks, Infrastructure, and Services*
- 4.8.7 -- *Building the Team and Initiating Engineering Processes* (conceiving, designing, implementing and operating)
- 4.8.8 -- *Managing Intellectual Property*

SUMMARY

This paper has presented the following key concepts:

- The CDIO Syllabus was designed to be a rational, detailed, and relatively complete taxonomy for the knowledge, skills, and attitudes that graduating engineers should possess; and, it has been stable for almost ten years
- Its high-level structure was shown to be consistent with the Four Pillars of Learning outlined by UNESCO
- The Syllabus was instrumental in the design of constructively aligned learning outcomes, curricula, teaching approaches, student learning assessment, and program evaluation, and was found to be an effective way in which faculty communicate and benchmark their practice
- The CDIO Syllabus showed very good alignment with other outcomes-based taxonomies developed by national accreditation and evaluation bodies, and in many cases, was found to be more comprehensive and more detailed
- Based on comparisons with other taxonomies, and the frequent user questions raised over the years, particularly concerning innovation, invention, internationalization and sustainability, modifications in content and in labeling have been incorporated into Version 2.0 of the CDIO Syllabus
- In order to meet the needs of programs that explicitly address engineering leadership and entrepreneurship, an optional extension to the CDIO Syllabus has been developed

Benefits of the CDIO Syllabus were shown to apply to individual faculty, students, the engineering world, and the larger academic community.

- The detail in the CDIO Syllabus allowed individual faculty to gain detailed insight into its content and objectives, contemplate the deployment of these skills into a curriculum, and prepare teaching and assessment plans
- Adopting and disseminating the CDIO Syllabus facilitated comprehensive and rigorous education in its topics that benefited
 - students who enter engineering practice or research
 - industry that will reap the rewards of new engineers prepared to take the reigns of leadership, and
 - humankind who will enjoy improvement to the quality of life that comes with better products and services
- Widespread adoption of the CDIO Syllabus also facilitated the sharing of best curricular and pedagogic approaches, and promoted the development of standardized assessment tools, which resulted in better outcomes-based assessment.

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APPENDIX A
CONDENSED CDIO SYLLABUS v2.0
JUNE 2011

- 1 DISCIPLINARY KNOWLEDGE AND REASONING**
 - 1.1 KNOWLEDGE OF UNDERLYING MATHEMATICS AND SCIENCES**
 - 1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE**
 - 1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, METHODS AND TOOLS**
- 2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES**
 - 2.1 ANALYTICAL REASONING AND PROBLEM SOLVING**
 - 2.1.1 Problem Identification and Formulation
 - 2.1.2 Modeling
 - 2.1.3 Estimation and Qualitative Analysis
 - 2.1.4 Analysis With Uncertainty
 - 2.1.5 Solution and Recommendation
 - 2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY**
 - 2.2.1 Hypothesis Formulation
 - 2.2.2 Survey of Print and Electronic Literature
 - 2.2.3 Experimental Inquiry
 - 2.2.4 Hypothesis Test and Defense
 - 2.3 SYSTEM THINKING**
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 - 2.3.2 Emergence and Interactions in Systems
 - 2.3.3 Prioritization and Focus
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 - 2.4.2 Perseverance, Urgency and Will to Deliver, Resourcefulness and Flexibility
 - 2.4.3 Creative Thinking
 - 2.4.4 Critical Thinking
 - 2.4.5 Self-awareness, Metacognition and Knowledge Integration
 - 2.4.6 Lifelong Learning and Educating
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 - 2.5.2 Professional Behavior
 - 2.5.3 Proactive Vision and Intention in Life
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 - 2.5.5 Equity and Diversity
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- 3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION**
 - 3.1 TEAMWORK**
 - 3.1.1 Forming Effective Teams
 - 3.1.2 Team Operation
 - 3.1.3 Team Growth and Evolution
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 - 3.1.5 Technical and Multidisciplinary Teaming
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 - 3.2.2 Communications Structure
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 - 3.2.4 Electronic/Multimedia Communication
 - 3.2.5 Graphical Communication
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 - 3.2.7 Inquiry, Listening and Dialog
 - 3.2.8 Negotiation, Compromise and Conflict Resolution
 - 3.2.9 Advocacy
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 - 3.3 COMMUNICATIONS IN FOREIGN LANGUAGES**
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- 4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS**
 - 4.1 EXTERNAL, SOCIETAL, AND ENVIRONMENTAL CONTEXT**
 - 4.1.1 Roles and Responsibility of Engineers
 - 4.1.2 The Impact of Engineering on Society and the Environment

- 4.1.3 Society's Regulation of Engineering
- 4.1.4 The Historical and Cultural Context
- 4.1.5 Contemporary Issues and Values
- 4.1.6 Developing a Global Perspective
- 4.1.7 Sustainability and the Need for Sustainable Development
- 4.2 ENTERPRISE AND BUSINESS CONTEXT**
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 - 4.2.2 Enterprise Stakeholders, Strategy and Goals
 - 4.2.3 Technical Entrepreneurship
 - 4.2.4 Working in Organizations
 - 4.2.5 Working in International Organizations
 - 4.2.6 New Technology Development and Assessment
 - 4.2.7 Engineering Project Finance and Economics
- 4.3 CONCEIVING, SYSTEMS ENGINEERING AND MANAGEMENT**
 - 4.3.1 Understanding Needs and Setting Goals
 - 4.3.2 Defining Function, Concept and Architecture
 - 4.3.3 System Engineering, Modeling and Interfaces
 - 4.3.4 Development Project Management
- 4.4 DESIGNING**
 - 4.4.1 The Design Process
 - 4.4.2 The Design Process Phasing and Approaches
 - 4.4.3 Utilization of Knowledge in Design
 - 4.4.4 Disciplinary Design
 - 4.4.5 Multidisciplinary Design
 - 4.4.6 Design for Sustainability, Safety, Aesthetics, Operability and other Objectives
- 4.5 IMPLEMENTING**
 - 4.5.1 Designing a Sustainable Implementation Process
 - 4.5.2 Hardware Manufacturing Process
 - 4.5.3 Software Implementing Process
 - 4.5.4 Hardware Software Integration
 - 4.5.5 Test, Verification, Validation, and Certification
 - 4.5.6 Implementation Management
- 4.6 OPERATING**
 - 4.6.1 Designing and Optimizing Sustainable and Safe Operations
 - 4.6.2 Training and Operations
 - 4.6.3 Supporting the System Life Cycle
 - 4.6.4 System Improvement and Evolution
 - 4.6.5 Disposal and Life-End Issues
 - 4.6.6 Operations Management

**CONDENSED EXTENDED CDIO SYLLABUS:
LEADERSHIP AND ENTREPRENEURSHIP**

4.7 LEADING ENGINEERING ENDEAVORS

Creating a Purposeful Vision

- 4.7.1 Identifying the Issue, Problem or Paradox
- 4.7.2 Thinking Creatively and Communicating Possibilities
- 4.7.3 Defining the Solution
- 4.7.4 Creating New Solution Concepts

Delivering on the Vision

- 4.7.5 Building and Leading an Organization and Extended Organization
- 4.7.6 Planning and Managing a Project to Completion
- 4.7.7 Exercising Project/Solution Judgment and Critical Reasoning
- 4.7.8 Innovation – the Conception, Design and Introduction of New Goods and Services
- 4.7.9 Invention – the Development of New Devices, Materials or Processes that Enable New Goods and Services
- 4.7.10 Implementation and Operation – the Creation and Operation of the Goods and Services that will Deliver Value

4.8 ENTREPRENEURSHIP

- 4.8.1 Company Founding, Formulation, Leadership and Organization
- 4.8.2 Business Plan Development
- 4.8.3 Company Capitalization and Finances
- 4.8.4 Innovative Product Marketing
- 4.8.5 Conceiving Products and Services around New Technologies
- 4.8.6 The Innovation System, Networks, Infrastructure and Services
- 4.8.7 Building the Team and Initiating Engineering Processes
- 4.8.8 Managing Intellectual Property

APPENDIX B

The CDIO Syllabus v2.0 June 2011

1 DISCIPLINARY KNOWLEDGE AND REASONING (UNESCO: LEARNING TO KNOW)

1.1 KNOWLEDGE OF UNDERLYING MATHEMATICS AND SCIENCES [3a]

- 1.1.1 *Mathematics (including statistics)*
- 1.1.2 *Physics*
- 1.1.3 *Chemistry*
- 1.1.4 *Biology*

1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE [3a]

1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, METHODS AND TOOLS [3k]

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES (UNESCO: LEARNING TO BE)

2.1 ANALYTIC REASONING AND PROBLEM SOLVING [3e]

- 2.1.1 *Problem Identification and Formulation*
 - Data and symptoms
 - Assumptions and sources of bias
 - Issue prioritization in context of overall goals
 - A plan of attack (incorporating model, analytical and numerical solutions, qualitative analysis, experimentation and consideration of uncertainty)
- 2.1.2 *Modeling*
 - Assumptions to simplify complex systems and environment
 - Conceptual and qualitative models
 - Quantitative models and simulations
- 2.1.3 *Estimation and Qualitative Analysis*
 - Orders of magnitude, bounds and trends
 - Tests for consistency and errors (limits, units, etc.)
 - The generalization of analytical solutions
- 2.1.4 *Analysis with Uncertainty*
 - Incomplete and ambiguous information
 - Probabilistic and statistical models of events and sequences
 - Engineering cost-benefit and risk analysis
 - Decision analysis
 - Margins and reserves
- 2.1.5 *Solution and Recommendation*
 - Problem solutions
 - Essential results of solutions and test data
 - Discrepancies in results
 - Summary recommendations
 - Possible improvements in the problem solving process

Reference is to UNESCO, *Four Pillars of Education* at <http://www.unesco.org/delors/fourpil.htm>.
The numbers and letters in parentheses refer to ABET EC 2010, Criteria 3a – 3 k.

2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY [3b]

2.2.1 *Hypothesis Formulation*

- Critical questions to be examined
- Hypotheses to be tested
- Controls and control groups

2.2.2 *Survey of Print and Electronic Literature*

- The literature and media research strategy
- Information search and identification using library, on-line and database tools
- Sorting and classifying the primary information
- The quality and reliability of information
- The essentials and innovations contained in the information
- Research questions that are unanswered
- Citations to references

2.2.3 *Experimental Inquiry*

- The experimental concept and strategy
- The precautions when humans are used in experiments
- Investigations based on social science methods
- Experiment construction
- Test protocols and experimental procedures
- Experimental measurements
- Experimental data
- Experimental data vs. available models

2.2.4 *Hypothesis Test and Defense*

- The statistical validity of data
- The limitations of data employed
- Conclusions, supported by data, needs and values
- Possible improvements in knowledge discovery process

2.3 SYSTEM THINKING

2.3.1 *Thinking Holistically*

- A system, its function and behavior, and its elements
- Trans-disciplinary approaches that ensure the system is understood from all relevant perspectives
- The societal, enterprise and technical context of the system
- The interactions external to the system, and the behavioral impact of the system

2.3.2 *Emergence and Interactions in Systems*

- The abstractions necessary to define and model the entities or elements of the system
- The important relationships, interactions and interfaces among elements
- The functional and behavioral properties (intended and unintended) that emerge from the system
- Evolutionary adaptation over time

2.3.3 *Prioritization and Focus*

- All factors relevant to the system in the whole
- The driving factors from among the whole
- Energy and resource allocations to resolve the driving issues

2.3.4 *Trade-offs, Judgment and Balance in Resolution*

- Tensions and factors to resolve through trade-offs
- Solutions that balance various factors, resolve tensions and optimize the system as a whole
- Flexible vs. optimal solutions over the system lifetime
- Possible improvements in the system thinking used

2.4 ATTITUDES, THOUGHT AND LEARNING

- 2.4.1 *Initiative and Willingness to Make Decisions in the Face of Uncertainty*
 The needs and opportunities for initiative
 Leadership in new endeavors, with a bias for appropriate action
 Decisions, based on the information at hand
 Development of a course of action
 The potential benefits and risks of an action or decision
- 2.4.2 *Perseverance, Urgency and Will to Deliver, Resourcefulness and Flexibility*
 Sense of responsibility for outcomes
 Self-confidence, courage and enthusiasm
 Determination to accomplish objectives
 The importance of hard work, intensity and attention to detail
 Definitive action, delivery of results and reporting on actions
 Adaptation to change
 Making ingenious use of the resources of the situation or group
 A readiness, willingness and ability to work independently
 A willingness to work with others, and to consider and embrace various viewpoints
 An acceptance of feedback, criticism and willingness to reflect and respond
 The balance between personal and professional life
- 2.4.3 *Creative Thinking*
 Conceptualization and abstraction
 Synthesis and generalization
 The process of invention
 The role of creativity in art, science, the humanities and technology
- 2.4.4 *Critical Thinking*
 Purpose and statement of the problem or issue
 Assumptions
 Logical arguments (and fallacies) and solutions
 Supporting evidence, facts and information
 Points of view and theories
 Conclusions and implications
 Reflection on the quality of the thinking
- 2.4.5 *Self-Awareness, Metacognition and Knowledge Integration*
 One's skills, interests, strengths and weaknesses
 The extent of one's abilities, and one's responsibility for self-improvement to overcome important weaknesses
 The importance of both depth and breadth of knowledge
 Identification of how effectively and in what way one is thinking
 Linking knowledge together and identifying the structure of knowledge
- 2.4.6 *Lifelong Learning and Educating [3i]*
 The motivation for continued self-education
 The skills of self-education
 One's own learning styles
 Relationships with mentors
 Enabling learning in others
- 2.4.7 *Time and Resource Management*
 Task prioritization
 The importance and/or urgency of tasks
 Efficient execution of tasks

2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES [3f]

- 2.5.1 *Ethics, Integrity and Social Responsibility*
 One's ethical standards and principles
 The moral courage to act on principle despite adversity

Reference is to UNESCO, *Four Pillars of Education* at <http://www.unesco.org/delors/fourpil.htm>.
 The numbers and letters in parentheses refer to ABET EC 2010, Criteria 3a – 3 k.

- The possibility of conflict between professionally ethical imperatives
- A commitment to service
- Truthfulness
- A commitment to help others and society more broadly
- 2.5.2 *Professional Behavior*
 - A professional bearing
 - Professional courtesy
 - International customs and norms of interpersonal contact
- 2.5.3 *Proactive Vision and Intention in Life*
 - A personal vision for one's future
 - Aspiration to exercise his/her potentials as a leader
 - One's portfolio of professional skills
 - Considering one's contributions to society
 - Inspiring others
- 2.5.4 *Staying Current on the World of Engineering*
 - The potential impact of new scientific discoveries
 - The social and technical impact of new technologies and innovations
 - A familiarity with current practices/technology in engineering
 - The links between engineering theory and practice
- 2.5.5 *Equity and Diversity*
 - A commitment to treat others with equity
 - Embracing diversity in groups and workforce
 - Accommodating diverse backgrounds
- 2.5.6 *Trust and Loyalty*
 - Loyalty to one's colleagues and team
 - Recognizing and emphasizing the contributions of others
 - Working to make others successful

3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION (UNESCO: LEARNING TO LIVE TOGETHER)

3.1 TEAMWORK [3d]

- 3.1.1 *Forming Effective Teams*
 - The stages of team formation and life cycle
 - Task and team processes
 - Team roles and responsibilities
 - The goals, needs and characteristics (works styles, cultural differences) of individual team members
 - The strengths and weaknesses of the team and its members
 - Ground rules on norms of team confidentiality, accountability and initiative
- 3.1.2 *Team Operation*
 - Goals and agenda
 - The planning and facilitation of effective meetings
 - Team ground rules
 - Effective communication (active listening, collaboration, providing and obtaining information)
 - Positive and effective feedback
 - The planning, scheduling and execution of a project
 - Solutions to problems (team creativity and decision making)
 - Conflict mediation, negotiation and resolution
 - Empowering those on the team

Reference is to UNESCO, *Four Pillars of Education* at <http://www.unesco.org/delors/fourpil.htm>.
The numbers and letters in parentheses refer to ABET EC 2010, Criteria 3a – 3 k.

- 3.1.3 *Team Growth and Evolution*
 - Strategies for reflection, assessment and self-assessment
 - Skills for team maintenance and growth
 - Skills for individual growth within the team
 - Strategies for team communication and reporting
- 3.1.4 *Team Leadership*
 - Team goals and objectives
 - Team process management
 - Leadership and facilitation styles (directing, coaching, supporting, delegating)
 - Approaches to motivation (incentives, example, recognition, etc.)
 - Representing the team to others
 - Mentoring and counseling
- 3.1.5 *Technical and Multidisciplinary Teaming*
 - Working in different types of teams:
 - Cross-disciplinary teams (including non-engineer)
 - Small team vs. large team
 - Distance, distributed and electronic environments
 - Technical collaboration with team members
 - Working with non-technical members and teams

3.2 COMMUNICATIONS [3g]

- 3.2.1 *Communications Strategy*
 - The communication situation
 - Communications objectives
 - The needs and character of the audience
 - The communication context
 - A communications strategy
 - The appropriate combination of media
 - A communication style (proposing, reviewing, collaborating, documenting, teaching)
 - The content and organization
- 3.2.2 *Communications Structure*
 - Logical, persuasive arguments
 - The appropriate structure and relationship amongst ideas
 - Relevant, credible, accurate supporting evidence
 - Conciseness, crispness, precision and clarity of language
 - Rhetorical factors (e.g. audience bias)
 - Cross-disciplinary cross-cultural communications
- 3.2.3 *Written Communication*
 - Writing with coherence and flow
 - Writing with correct spelling, punctuation and grammar
 - Formatting the document
 - Technical writing
 - Various written styles (informal, formal memos, reports, resume, etc.)
- 3.2.4 *Electronic/Multimedia Communication*
 - Preparing electronic presentations
 - The norms associated with the use of e-mail, voice mail, and videoconferencing
 - Various electronic styles (charts, web, etc)
- 3.2.5 *Graphical Communications*
 - Sketching and drawing
 - Construction of tables, graphs and charts
 - Formal technical drawings and renderings
 - Use of graphical tools

Reference is to UNESCO, *Four Pillars of Education* at <http://www.unesco.org/delors/fourpil.htm>.
The numbers and letters in parentheses refer to ABET EC 2010, Criteria 3a – 3 k.

- 3.2.6 *Oral Presentation*
 - Preparing presentations and supporting media with appropriate language, style, timing and flow
 - Appropriate nonverbal communications (gestures, eye contact, poise)
 - Answering questions effectively
- 3.2.7 *Inquiry, Listening and Dialog*
 - Listening carefully to others, with the intention to understand
 - Asking thoughtful questions of others
 - Processing diverse points of view
 - Constructive dialog
 - Recognizing ideas that may be better than your own
- 3.2.8 *Negotiation, Compromise and Conflict Resolution*
 - Identifying potential disagreements, tensions or conflicts
 - Negotiation to find acceptable solutions
 - Reaching agreement without compromising fundamental principles
 - Diffusing conflicts
- 3.2.9 *Advocacy*
 - Clearly explaining one's point of view
 - Explaining how one reached an interpretation or conclusion
 - Assessing how well you are understood
 - Adjusting approach to advocacy on audience characteristics
- 3.2.10 *Establishing Diverse Connections and Networking*
 - Appreciating those with different skills, cultures or experiences
 - Engaging and connecting with diverse individuals
 - Building extended social networks
 - Activating and using networks to achieve goals

3.3 COMMUNICATIONS IN FOREIGN LANGUAGES

- 3.3.1 *Communications in English*
- 3.3.2 *Communications in Languages of Regional Commerce and Industry*
- 3.3.3 *Communications in Other Languages*

4 CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS (UNESCO: LEARNING TO DO)

4.1 EXTERNAL, SOCIETAL AND ENVIRONMENTAL CONTEXT [3h]

- 4.1.1 *Roles and Responsibility of Engineers*
 - The goals and roles of the engineering profession
 - The responsibilities of engineers to society and a sustainable future
- 4.1.2 *The Impact of Engineering on Society and the Environment*
 - The impact of engineering on the environmental, social, knowledge and economic systems in modern culture
- 4.1.3 *Society's Regulation of Engineering*
 - The role of society and its agents to regulate engineering
 - The way in which legal and political systems regulate and influence engineering
 - How professional societies license and set standards
 - How intellectual property is created, utilized and defended
- 4.1.4 *The Historical and Cultural Context*
 - The diverse nature and history of human societies as well as their literary, philosophical and artistic traditions

Reference is to UNESCO, *Four Pillars of Education* at <http://www.unesco.org/delors/fourpil.htm>.
The numbers and letters in parentheses refer to ABET EC 2010, Criteria 3a – 3 k.

The discourse and analysis appropriate to the discussion of language, thought and values

4.1.5 *Contemporary Issues and Values [3j]*

The important contemporary political, social, legal and environmental issues and values

The processes by which contemporary values are set, and one's role in these processes

The mechanisms for expansion and diffusion of knowledge

4.1.6 *Developing a Global Perspective*

The internationalization of human activity

The similarities and differences in the political, social, economic, business and technical norms of various cultures

International and intergovernmental agreements and alliances

4.1.7 *Sustainability and the Need for Sustainable Development*

Definition of sustainability

Goals and importance of sustainability

Principles of sustainability

Need to apply sustainability principles in engineering endeavors

4.2 ENTERPRISE AND BUSINESS CONTEXT

4.2.1 *Appreciating Different Enterprise Cultures*

The differences in process, culture, and metrics of success in various enterprise cultures:

Corporate vs. academic vs. governmental vs. non-profit/NGO

Market vs. policy driven

Large vs. small

Centralized vs. distributed

Research and development vs. operations

Mature vs. growth phase vs. entrepreneurial

Longer vs. faster development cycles

With vs. without the participation of organized labor

4.2.2 *Enterprise Stakeholders, Strategy and Goals*

The stakeholders and beneficiaries of an enterprise (owners, employees, customers, etc.)

Obligations to stakeholders

The mission, scope and goals of the enterprise

Enterprise strategy and resource allocation

An enterprise's core competence and markets

Key alliances and supplier relations

4.2.3 *Technical Entrepreneurship*

Entrepreneurial opportunities that can be addressed by technology

Technologies that can create new products and systems

Entrepreneurial finance and organization

4.2.4 *Working in Organizations*

The function of management

Various roles and responsibilities in an organization

The roles of functional and program organizations

Working effectively within hierarchy and organizations

Change, dynamics and evolution in organizations

4.2.5 *Working in International Organizations*

Culture and tradition of enterprise as a reflection of national culture

Equivalence of qualifications and degrees

Governmental regulation of international work

4.2.6 *New Technology Development and Assessment*

The research and technology development process

Identifying and assessing technologies

Technology development roadmaps

Reference is to UNESCO, *Four Pillars of Education* at <http://www.unesco.org/delors/fourpil.htm>.

The numbers and letters in parentheses refer to ABET EC 2010, Criteria 3a – 3 k.

- Intellectual property regimes and patents
- 4.2.7 *Engineering Project Finance and Economics*
 - Financial and managerial goals and metrics
 - Project finance – investments, return, timing
 - Financial planning and control
 - Impact of projects on enterprise finance, income and cash

4.3 CONCEIVING, SYSTEM ENGINEERING AND MANAGEMENT [3c]

- 4.3.1 *Understanding Needs and Setting Goals*
 - Needs and opportunities
 - Customer needs, and those of the market
 - Opportunities that derive from new technology or latent needs
 - Environmental needs
 - Factors that set the context of the system goals
 - Enterprise goals, strategies, capabilities and alliances
 - Competitors and benchmarking information
 - Ethical, social, environmental, legal and regulatory influences
 - The probability of change in the factors that influence the system, its goals and resources available
 - System goals and requirements
 - The language/format of goals and requirements
 - Initial target goals (based on needs, opportunities and other influences)
 - System performance metrics
 - Requirement completeness and consistency
- 4.3.2 *Defining Function, Concept and Architecture*
 - Necessary system functions (and behavioral specifications)
 - System concepts
 - Incorporation of the appropriate level of technology
 - Trade-offs among and recombination of concepts
 - High-level architectural form and structure
 - The decomposition of form into elements, assignment of function to elements, and definition of interfaces
- 4.3.3 *System Engineering, Modeling and Interfaces*
 - Appropriate models of technical performance and other attributes
 - Consideration of implementation and operations
 - Life cycle value and costs (design, implementation, operations, opportunity, etc.)
 - Trade-offs among various goals, function, concept and structure and iteration until convergence
 - Plans for interface management
- 4.3.4 *Development Project Management*
 - Project control for cost, performance and schedule
 - Appropriate transition points and reviews
 - Configuration management and documentation
 - Performance compared to baseline
 - Earned value recognition
 - The estimation and allocation of resources
 - Risks and alternatives
 - Possible development process improvements

4.4 DESIGNING [3c]

- 4.4.1 *The Design Process*
 - Requirements for each element or component derived from system level goals and requirements
 - Alternatives in design

Reference is to UNESCO, *Four Pillars of Education* at <http://www.unesco.org/delors/fourpil.htm>.
The numbers and letters in parentheses refer to ABET EC 2010, Criteria 3a – 3 k.

- The initial design
- Life cycle consideration in design
- Experimental prototypes and test articles in design development
- Appropriate optimization in the presence of constraints
- Iteration until convergence
- The final design
- Accommodation of changing requirements
- 4.4.2 *The Design Process Phasing and Approaches*
 - The activities in the phases of system design (e.g. conceptual, preliminary and detailed design)
 - Process models appropriate for particular development projects (waterfall, spiral, concurrent, etc.)
 - The process for single, platform and derivative products
- 4.4.3 *Utilization of Knowledge in Design*
 - Technical and scientific knowledge
 - Modes of thought (problem solving, inquiry, system thinking, creative and critical thinking)
 - Prior work in the field, standardization and reuse of designs (including reverse engineering and refactoring, redesign)
 - Design knowledge capture
- 4.4.4 *Disciplinary Design*
 - Appropriate techniques, tools and processes
 - Design tool calibration and validation
 - Quantitative analysis of alternatives
 - Modeling, simulation and test
 - Analytical refinement of the design
- 4.4.5 *Multidisciplinary Design*
 - Interactions between disciplines
 - Dissimilar conventions and assumptions
 - Differences in the maturity of disciplinary models
 - Multidisciplinary design environments
 - Multidisciplinary design
- 4.4.6 *Design for Sustainability, Safety, Aesthetics, Operability and Other Objectives*
 - Design for:
 - Performance, quality, robustness, life cycle cost and value
 - Sustainability
 - Safety and security
 - Aesthetics
 - Human factors, interaction and supervision
 - Implementation, verification, test and environmental sustainability
 - Operations
 - Maintainability, dependability and reliability
 - Evolution, product improvement
 - Retirement, reusability and recycling

4.5 IMPLEMENTING [3c]

- 4.5.1 *Designing a Sustainable Implementation Process*
 - The goals and metrics for implementation performance, cost and quality
 - The implementation system design:
 - Task allocation and cell/unit layout
 - Workflow
 - Considerations for human user/operators
 - Consideration of sustainability

Reference is to UNESCO, *Four Pillars of Education* at <http://www.unesco.org/delors/fourpil.htm>.
The numbers and letters in parentheses refer to ABET EC 2010, Criteria 3a – 3 k.

- 4.5.2 *Hardware Manufacturing Process*
 - The manufacturing of parts
 - The assembly of parts into larger constructs
 - Tolerances, variability, key characteristics and statistical process control
- 4.5.3 *Software Implementing Process*
 - The break down of high-level components into module designs (including algorithms and data structures)
 - Algorithms (data structures, control flow, data flow)
 - The programming language and paradigms
 - The low-level design (coding)
 - The system build
- 4.5.4 *Hardware Software Integration*
 - The integration of software in electronic hardware (size of processor, communications, etc.)
 - The integration of software with sensor, actuators and mechanical hardware
 - Hardware/software function and safety
- 4.5.5 *Test, Verification, Validation and Certification*
 - Test and analysis procedures (hardware vs. software, acceptance vs. qualification)
 - The verification of performance to system requirements
 - The validation of performance to customer needs
 - The certification to standards
- 4.5.6 *Implementation Management*
 - The organization and structure for implementation
 - Sourcing and partnering
 - Supply chains and logistics
 - Control of implementation cost, performance and schedule
 - Quality assurance
 - Human health and safety
 - Environmental security
 - Possible implementation process improvements

4.6 OPERATING [3c]

- 4.6.1 *Designing and Optimizing Sustainable and Safe Operations*
 - The goals and metrics for operational performance, cost and value
 - Sustainable operations
 - Safe and secure operations
 - Operations process architecture and development
 - Operations (and mission) analysis and modeling
- 4.6.2 *Training and Operations*
 - Training for professional operations:
 - Simulation
 - Instruction and programs
 - Procedures
 - Education for consumer operation
 - Operations processes
 - Operations process interactions
- 4.6.3 *Supporting the System Life Cycle*
 - Maintenance and logistics
 - Life cycle performance and reliability
 - Life cycle value and costs
 - Feedback to facilitate system improvement

4.6.4 *System Improvement and Evolution*

- Pre-planned product improvement
- Improvements based on needs observed in operation
- Evolutionary system upgrades
- Contingency improvements/solutions resulting from operational necessity

4.6.5 *Disposal and Life-End Issues*

- The end of useful life
- Disposal options
- Residual value at life-end
- Environmental considerations for disposal

4.6.6 *Operations Management*

- The organization and structure for operations
- Partnerships and alliances
- Control of operations cost, performance and scheduling
- Quality and safety assurance
- Possible operations process improvements
- Life cycle management
- Human health and safety
- Environmental security

The Extended CDIO Syllabus: Leadership and Entrepreneurship

This extension to the CDIO Syllabus is provided as a resource for programs that seek to respond to stakeholder expressed needs in the areas of Engineering Leadership and Entrepreneurship

4.7 LEADING ENGINEERING ENDEAVORS

Engineering Leadership builds on factors already included above, including:

- **Attitudes of Leadership – Core Personal Values and Character**, including topics in Attitudes, Thought and Learning (2.4), and in Ethics, Equity and Other Responsibilities (2.5)
- **Relating to Others**, including topics in Teamwork (3.1), Communications (3.2) and potentially Communications in Foreign Languages (3.3)
- **Making Sense of Context**, including topics in External, Societal and Environmental Context (4.1), Enterprise and Business Context (4.2) Conceiving, Systems Engineering and Management (4.3) and System Thinking (2.3)

In addition there are several topics that constitute creating a **Purposeful Vision**:

4.7.1 *Identifying the Issue, Problem or Paradox (which builds on Understanding Needs and Setting Goals 4.3.1)*

Synthesizing the understanding of needs or opportunities (that technical systems can address)

Clarifying the central issues

Framing the problem to be solved

Identifying the underlying paradox to be examined

4.7.2 *Thinking Creatively and Communicating Possibilities (which builds on and expands Creative Thinking 2.4.3)*

How to create new ideas and approaches

New visions of technical systems that meet the needs of customers and society

Communicating visions for products and enterprises

Compelling visions for the future

4.7.3 *Defining the Solution (which builds on and expands Understanding Needs and Setting Goals 4.3.1)*

The vision for the engineering solution

Achievable goals for quality performance, budget and schedule

Consideration of customer and beneficiary

Consideration of technology options

Consideration of regulatory, political and competitive forces

4.7.4 *Creating New Solution Concepts (which builds on and expands 4.3.2 and 4.3.3)*

Setting requirements and specifications

The high-level concept for the solution

Architecture and interfaces

Alignment with other projects of the enterprise

Alignment with enterprise strategy, resources and infrastructure

And several topics that lead to **Delivering on the Vision**:

4.7.5 *Building and Leading an Organization and Extended Organization (which builds on 4.2.4 and 4.2.5)*

Recruiting key team members with complementary skills

Start-up of team processes, and technical interchange

Defining roles, responsibilities and incentives

Leading group decision-making

Reference is to UNESCO, *Four Pillars of Education* at <http://www.unesco.org/delors/fourpil.htm>.
The numbers and letters in parentheses refer to ABET EC 2010, Criteria 3a – 3 k.

- Assessing group progress and performance
- Building the competence of others and succession
- Partnering with external competence
- 4.7.6 *Planning and Managing a Project to Completion (which builds on 4.3.4)*
 - Plans of action and alternatives to deliver completed projects on time
 - Deviation from plan, and re-planning
 - Managing human, time, financial and technical resources to meet plan
 - Program risk, configuration and documentation
 - Program economics and the impact of decisions on them
- 4.7.7 *Exercising Project/Solution Judgment and Critical Reasoning (which builds on 2.3.4 and 2.4.4)*
 - Making complex technical decisions with uncertain and incomplete information
 - Questioning and critically evaluating the decisions of others
 - Corroborating inputs from several sources
 - Evaluating evidence and identifying the validity of key assumptions
 - Understanding alternatives that are proposed by others
 - Judging the expected evolution of all solutions in the future
- 4.7.8 *Innovation – the Conception, Design and Introduction of New Goods and Services (which is the leadership of 4.3 and 4.4)*
 - Designing and introducing new goods and services to the marketplace
 - Designing solutions to meet customer and societal needs
 - Designing solutions with the appropriate balance of new and existing technology
 - Robust, flexible and adaptable products
 - Consideration of current and future competition
 - Validating the effectiveness of the solution
- 4.7.9 *Invention – the Development of New Devices, Materials or Processes that Enable New Goods and Services (which builds on 4.2.6)*
 - Science and technology basis and options
 - Imagining possibilities
 - Inventing a practical device or process that enables a new product or solution
 - Adherence to intellectual property regimes
- 4.7.10 *Implementation and Operation – the Creation and Operation of the Goods and Services that will Deliver Value (which are the leadership of 4.5 and 4.6)*
 - Leading implementing and operating
 - Importance of quality
 - Safe operations
 - Operations to deliver value to the customer and society

These last three items are in fact the leadership of the core processes of engineering: conceiving, designing, implementing and operating

4.8 ENGINEERING ENTREPRENEURSHIP

Engineering Entrepreneurship includes by reference all of the aspects of Societal and Enterprise Context (4.1 and 4.2), all of the skills of Conceiving, Designing, Implementing and Operating (4.3 – 4.6) and all of the elements of Engineering Leadership (4.7).

In addition, there are the entrepreneurship specific skills:

- 4.8.1 *Company Founding, Formulation, Leadership and Organization*
 - Creating the corporate entity and financial infrastructure
 - Team of supporting partners (bank, lawyer, accounting, etc.)
 - Consideration of local labor law and practices
 - The founding leadership team
 - The initial organization
 - The board of the company

Reference is to UNESCO, *Four Pillars of Education* at <http://www.unesco.org/delors/fourpil.htm>.
The numbers and letters in parentheses refer to ABET EC 2010, Criteria 3a – 3 k.

- Advisors to the company
- 4.8.2 *Business Plan Development*
 - A need in the world that you will fill
 - A technology that can become a product
 - A team that can develop the product
 - Plan for development
 - Uses of capital
 - Liquidity strategy
- 4.8.3 *Company Capitalization and Finances*
 - Capital needed, and timing of need (to reach next major milestone)
 - Investors as sources of capital
 - Alternative sources of capital (government, etc.)
 - Structure of investment (terms, price, etc.)
 - Financial analysis for investors
 - Management of finances
 - Expenditures against intermediate milestones of progress
- 4.8.4 *Innovative Product Marketing*
 - Size of potential market
 - Competitive analyses
 - Penetration of market
 - Product positioning
 - Relationships with customers
 - Product pricing
 - Sales initiation
 - Distribution to customers
- 4.8.5 *Conceiving Products and Services around New Technologies*
 - New technologies available
 - Assessing the readiness of technology
 - Assessing the ability of your enterprise to innovate based on the technology
 - Assessing the product impact of the technology
 - Accessing the technologies through partnerships, licenses, etc.
 - A team to productize the technology
- 4.8.6 *The Innovation System, Networks, Infrastructure and Services*
 - Relationships for enterprise success
 - Mentoring of the enterprise leadership
 - Supporting financial services
 - Investor networks
 - Suppliers
- 4.8.7 *Building the Team and Initiating Engineering Processes (conceiving, designing, implementing and operating)*
 - Hiring the right skill mix
 - Technical process startup
 - Building an engineering culture
 - Establishing enterprise processes
- 4.8.8 *Managing Intellectual Property*
 - IP landscape for your product or technology
 - IP strategy – offensive and defensive
 - Filing patents and provisional patents
 - IP legal support
 - Entrepreneurial opportunities that can be addressed by technology
 - Technologies that can create new products and systems
 - Entrepreneurial finance and organization

Reference is to UNESCO, *Four Pillars of Education* at <http://www.unesco.org/delors/fourpil.htm>.
The numbers and letters in parentheses refer to ABET EC 2010, Criteria 3a – 3 k.

CONCEPT QUESTIONS IN ENGINEERING: THE BEGINNINGS OF A SHARED COLLECTION

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ABSTRACT

Concept questions (CQs) have been pioneered by Eric Mazur and others, and popularised by the Force Concept Inventory (FCI). CQs require that the student thinks about and applies engineering principles and ideally require the recall of few, if any, facts or data. At present they are available (or at least published) in just a few areas of engineering. A review of the available literature reveals only a dozen or so examples of the systematic use of concept questions. This session will be dedicated to sharing what is currently available and stimulating the writing of further CQs in currently under-populated areas of engineering.

KEYWORDS

Concept questions; assessment; engineering principles

INTRODUCTION TO CONCEPT QUESTIONS

Concept questions are questions for students which seek to explore their understanding rather than their recall or knowledge. In higher education they have been developed by teachers in various fields, but principally in physical sciences, over the twenty years since about 1991. Concept questions could be used for either formative or summative assessment, but one of the huge advantages they offer is the potential for the teacher to discover the misconceptions held by his or her students in time to do something about this deficit. Consequently there are more reports of concept questions being used in class, or in pre-course surveys, than in summative examinations. [e.g. 1, 2].

It is probably helpful to illustrate the power of concept questions by using an example from the engineering education domain, rather than from a technical domain such as mechanics or thermodynamics. Let us consider possible questions about assessment:

1. List ten ways in which a taught course might be assessed;
2. Describe, giving advantages and disadvantages for each, three ways in which a course might be assessed;
3. Would you devise the summative assessment for a course before or after assembling the content to be taught? Explain your answer.

Question 1 simply tests recall of facts (whether these were included in a lecture or in a source found by the student). Question 2 tests recall of facts, but also requires a little more detail about each. This detail might arise from understanding but equally might demonstrate better recall. (I

have seen a recent example of two complete pages of detail being recalled by a student in a closed examination – demonstrating no understanding whatsoever.) Question 3 is a concept question. In order to answer it the student would need to understand not only the meaning of the phrase “summative assessment” but also its purpose and its relationship to the “taught” material and the intended learning outcomes of the course. Unless the students had previously been presented with the identical question, recall of facts (or a model answer) is of very little use in answering it.

Concept questions were originally used by Mazur as a focus for student engagement in large classes and were associated with responses via a “clicker” (personal response system). However this is merely one way in which such questions can be deployed. Many education researchers have also used sets of concept questions as a research tool with which to investigate the extent of, and reasons for, student misconceptions about key concepts in engineering and physical science.[e.g. 3, 4, 5, 9, 11]

Many good concept questions offer “distractor” answers which reflect common misconceptions, but the questions do not necessarily have to be multiple choice. Some equally good questions ask for open-ended responses in free text. Mazur [I think, but cannot find the reference!] recommends marking these on a very coarse scale, analogous to that used when refereeing a paper (e.g. 3 for “accept unchanged”, 2 for “minor corrections needed”, 1 for “major re-write needed” and 0 for “reject”. The analogous rubric for a concept question is clear.) Such marking does not require a long time per answer.

In this paper I want to outline the small number of published sets of concept questions which are available in the engineering domain, and encourage CDIO members to contribute to extending this resource.

EXISTING SETS OF QUESTIONS

The best known set of concept questions is probably the Force Concept Inventory (FCI) devised by Hestenes [6] and accessible at <http://modeling.asu.edu/r%26e/> and in Mazur’s book [1]. Gray and a team of co-workers have assembled a Dynamics Concept Inventory of 29 questions [7], but in order to forestall student discovery and the sharing of answers, the inventory is only accessible to faculty on application to the team. Mazur published several sets of questions with his book “Peer Instruction” in 1997 [1] and these cover a range of topics drawn from undergraduate physics. This is the largest set of questions in a single open source and many of the questions are applicable to engineering students.

Good concept questions are quite time-consuming (and intellectually challenging) to produce, so for obvious reasons it is sensible not to release them to students but to use them only in controlled class situations. Mazur for one, and maybe others, have also regularly used concept questions in formal summative examinations [1].

In order to give a flavour of the questions which have already been written, I have appended a small selection. To reduce the risk of letting good question sets out of the bag, I have not credited each individual question with its provenance, except to say that the source of every question has been cited in this paper [8, 10, 12, 13 and other references] .

A CDIO CONCEPT QUESTION RESOURCE

I propose that we establish a shared CDIO bank of concept questions. This would include (with permission from the authors) existing sets of questions but would be considerably enhanced by the addition of questions written by faculty members of CDIO member institutions. As a start I propose that everyone at this conference should devise a single question in their own domain of specialisation.

As a second step I am willing to collect and coordinate this question bank, either or both via Mendeley [www.mendeley.com] and/or Dropbox [www.dropbox.com]. In both cases I am happy to give access to any CDIO Faculty member or other bona fide engineering academic who wishes to contact me. Mendeley is an excellent package for sharing pdf resources but has a number of sharers limited by the rate of subscription so cannot be completely open to all those who request access. I will give first preference to CDIO faculty.

At the conference in Copenhagen I will be asking all delegates to submit concept questions for inclusion in this resource. It would be useful to look through Mazur's book first, because this is the largest single pre-existing resource. I have also compared the available concept questions with the set of concepts which the lecturers of first year classes claim to teach at the University of Liverpool. Topics which appear to be currently under-supplied with concept questions include the following (in no particular order):

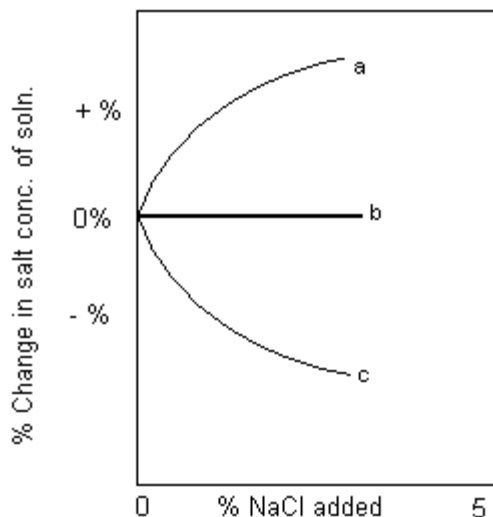
- Vectors
- Bending moment diagrams
- Tracking a load through a structure
- Non-dimensional groups
- Bernoulli equation
- Thermodynamic reversibility/irreversibility
- The logical ideas behind a computer program
- Systems thinking
- The link between properties and microstructure
- Interaction between basic deformation modes (e.g. bending and torsion)
- Crystallinity and its implications

These topics require a conceptual grasp, but there are many other first-year topics which require knowledge and – especially – a clear understanding of vocabulary. A common set of questions in these domains would also be useful but is not the subject of this paper.

SOME EXAMPLES OF CONCEPT QUESTIONS

1. Draw the free body diagram for a coin just after it has been tossed. [Alternatively: What is the force on a coin just after it has been tossed?] Are the forces on the coin greater on the way up or the way down? Ignore air friction.
2. H₂O is heated in a frictionless piston-and cylinder arrangement, where the piston mass and the atmospheric pressure above it are constant. The pressure of the H₂O will: (a) increase (b) remain constant (c) decrease (d) need more information.
3. About a teaspoon of water-saturated salt sits on the bottom of a beaker. If the solution is allowed to sit for 24 hours and have some of the water evaporate, which curve represents the change in concentration of the salt in the solution from time t₁ to t₂?

(Circle a or b or c) PLEASE EXPLAIN. [Diagrams in concept questions rarely need to be more sophisticated than this.]



4. A large truck collides head-on with a small car. During the collision:
- The truck exerts a greater amount of force on the car than the car exerts on the truck;
 - The car exerts a greater amount of force on the truck than the truck exerts on the car;
 - Neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck;
 - The truck exerts a force on the car but the car does not exert a force on the truck;
 - The truck exerts the same amount of force on the car as the car exerts on the truck.
5. A system consisting of a quantity of ideal gas is in equilibrium state "A". It is slowly heated and as it expands its pressure varies. It ends up in equilibrium state "B". Now suppose that the same quantity of ideal gas again starts in state "A" but undergoes a different thermodynamic process (i.e. follows a different path on a P-V diagram) only to end up again in the same state "B" as before. Consider the net work done by the system and the net heat absorbed by the system during these two different processes. Which of these statements is true?
- The work done may be different in the two processes but the heat absorbed must be the same;
 - The work done must be the same in the two processes, but the heat absorbed may be different;
 - The work done may be different in the two processes, and the heat absorbed may be different in the two processes;
 - Both the work done and the heat absorbed must be the same in the two processes, but are not equal to zero;
 - Both the work done and the heat absorbed by the system must be equal to zero in both processes.
- [Each of the five answers was selected by some students.]
6. If atomic bonding in metal A is weaker than metal B, then metal A has:
- lower melting point

- b) lower brittleness
 - c) lower electrical conductivity
 - d) lower thermal expansion coefficient
 - e) lower density
7. If you unwrap a new piece of modeling clay that is a rectangular solid 4cm x 4cm x 16cm, which one of the following would most increase its surface area?
- a) Press down on a long side (making it, e.g. about 16 x 8 x 2 cm³)
 - b) Form it into a cube, about 6.5 cm per side.
 - c) Form it into a cylinder, keeping the length about 16cm.
 - d) Make a sphere.
8. What do these three processes have in common?
- Rust forming on iron nail
Water evaporating from a dish
A piece of candy dissolving in your mouth
- a) The rate of change depends on the mass of the substance.
 - b) All three processes involve a change in phase.
 - c) All three processes are chemical reactions.
 - d) All three processes occur at the surface of the substance.
 - e) All three processes depend on the solubility of the substance.
9. You are in an elevator travelling upwards at constant velocity. Suddenly you drop your keys: It so happens that when they strike the floor they are at the same height above ground level as when they left your hand. The keys fall dead on the floor without bouncing. Make a single graph showing qualitatively the height above ground of both the keys and the elevator as a function of time, starting before the keys are released until after they strike the floor.

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BIOGRAPHICAL INFORMATION

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AIR PUMP – IMPROVEMENT OF A ‘SKYSCRAPER-TYPE’ EXERCISE FOR MECHANICAL ENGINEERING PROGRAMS

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ABSTRACT

‘Air Pump 2’ is a design-build-test (DBT) exercise at the start of the first-year project module in Mechanical Engineering (ME) at École Polytechnique (EPM). ME students have gained prior experience at ‘Air Pump 1’ 16 weeks before, a playful challenge on Orientation week. In ‘Air pump 2’, teams of 4-6 students work from a ‘functional requirement’ sheet. The context is that of corporations competing for a ‘contract’ for 10,000 pumps. The flow-pressure-volume pre-tests of a prototype, materialised by apparatuses not fully appropriate, set the context for a ‘Test’ phase in two rounds, on ‘new’ and ‘aged’ pumps. Students keep track of test scores and costs (an opportunity to discuss breach of ethical behaviour). A 20 min class reflection follows a first 10 min individual reflection without prompts. On the upside, many students do not take the embedded 10 min break, and work on their pump. On the downside, only a minority pursue the reflection off-hours, and too small a percentage of the pumps abide by the constraints or actually work. Informal surveys point to this as a probable cause of disengagement from subsequent autonomous reflection.

KEYWORDS

Air pump; Design-Build-Test; Experiential learning; Collaborative improvement.

INTRODUCTION

Mechanical engineers often design from functional specifications and reverse engineering, convey their ideas with sketches, make good use of morphological analysis in the selection of a conceptual solution, and weigh their choices between standard and custom-made parts. At EPM, the Mechanical Engineering program sought an alternative to the more Civil Engineering oriented ‘Skyscraper’ DBT exercise known to CDIO regulars [1]. Experimented with in the fall of 2009, ME has since used and improved the ‘Air pump’ every semester (ME has some 200 students incoming in the fall and 50 starting in the winter semesters).

This paper summarises our experience with the ‘Air pump’, a DBT exercise used to help the students develop the tendency to seek structure when learning how to solve problems of all kinds. It reviews reasons in favour of a mechanical system DBT-type exercise, together with the rationale behind its recurrent use. The material conditions under which to carry the exercise follows, with building material, testing apparatuses, and room setup. Group and team sizes, and goal structuring is presented. Finally, results cover the necessities of sketching, the simplification of goals, the multiple ways “creativity” circumvents the basic characteristics of a normal working pump, and weaknesses in the testing apparatuses. Our observations as to the small percentage of pumps that incorporate one-way valves, the even smaller percentage that reasonably work as pumps complete the results, and the outstanding capabilities of students to make the best of this learning situation complete the paper.

REASONS

Why have a son that resembles the father not

The merits of the ‘Skyscraper’ are unquestionable. Design-Build-Test (DBT) experiences and full courses have been surveyed, and found — over and above the training of design skills — to improve motivation, understanding of engineering, and non-technical skills [2].

An exercise more aligned with the discipline of the junior students, who can then relate more intensely to the design would better secure potential benefits. Although deemed obvious, this statement leaves something to be desired. For instance, too few students appreciate stretching out of their specialty before they actually explore diversity: Mechanical Engineering students dislike having to take Electrical Engineering courses until they discover Mechatronics. Are we to foster monolithic specialties for that reason? Nevertheless, classical Mechanical Engineering deals mostly with powered mechanisms that produce external effects due to moving parts, fluids and the laws of thermodynamics, and the ‘Skyscraper’ does not share these characteristics.

Air pumps come in a variety of sizes, shapes, concepts (bellows, piston,...) and stroke (single, double). Some hidden constituents are most critical. Volume analysis is within the reach of college students (volume of a cylinder, a cone, a prism,...). Leaks are mostly localised at the interface of moving parts, unless the pump is ill assembled. Pumps can be easily tested for flow, pressure and volume, and accommodate multiple technical criteria as goals. Pumps can be made to satisfy complementary functional requirements (“must be aesthetical”,...). Constraints can be imposed (minimum cubic centimetres displaced per stroke,...).

Air pumps provide the opportunity to present the problem as a case of functional analysis. The students design, build, and test a mechanism. They conceive from a description of the needs expressed as the result of a functional analysis: primary and complementary functions, constraints, and functional criteria. Students being “exposed to” functional analysis adds to the merits of the DBT (and they could be “exposed to” multiple-criteria based goal-equation optimisation and risk assessment).

Why the early bird catches the worm

Upon entering university, students commit themselves to the unknown, gradually discover a new learning environment, and decode the characteristics — one by one — of a new context they must integrate quickly. As a source of difficulties, students work mainly from preliminary *a priori* representations of the expectations. Some advocate that the earlier the student can validate and calibrate these representations, the easier and more successful his adaptation will be. A significant DBT provides a meaningful and comprehensive exercise to challenge these representations early in the curriculum.

The first day of Orientation week capitalises on ‘Air Pump 1’ as a relaxed playful challenge. Forced randomness in the formation of teams ensures that new students mingle. Senior students act as mentors. First year teachers stand by the test stands for the pumps, break the ice, and question the students about their pumps and tests. The exercise has the new students gather a common experience over which to present the curriculum at the end of “first day”. This common-experience-based questioning and presentation also should help the students start calibrating their *a priori* representations of our expectations.

The first day of the introductory project module one semester later builds on ‘Air pump 2’: an immediate, structured, and criteria-based design-build-test exercise, starting from the tabular output of a functional analysis. It thereafter forms the basis of the presentation about the project module. Again, we hope a common-experience-based reflection and presentation will help students to build teams with a common representation of our expectations in the module.

Why twice offer the same snare to the fox

Every student enters 'Air pump 2' with the prior experience of 'Air pump 1', where the forced randomness of team memberships reasonably ensures that different prior designs of Orientation week are regrouped at the onset of 'Air pump 2'. New teams start with multiple concepts to describe, discuss, compare, and choose from. A context normally created by brainstorming and morphological analysis, when methodology replaces the availability of prior designs. Group behaviour in 'Air pump 2' is thus kin to *acceleration by apprenticeship*.

From Gray and Feldman [3], the success of *apprenticeship* rests on a tendency to acquire knowledge and develop skills through interactions with more competent team members, and on a preference to perform new tasks in collaboration with others before trying them on our own. With respect to any of the prior design — taken separately — one mate is a “more competent team member”. All thus have equal opportunity to enjoy the status. Only communication and teamwork skills, and not the absence of prior knowledge, would then determine team dynamics... given prior designs all had equal value.

The well-known aspects of *work*, *affection*, and *power* (*achievement*, *affiliation*, and *power*) affect individuals and groups. S. Landry proposes a model postulating these aspects translate into dynamic zones, the chaotically-cyclical evolution of the group thus taking specific stakes into account as the group travels in and migrates between these three zones, until *group convergence* into a working merged zone has occurred [4]. First occurrences are not very efficient in a group. By repeating an exercise that students can trace to a playful context, and by helping provide “equal opportunity” about the potential contribution of all in the group, we hope to alleviate the contrary effects of the initial state of *divergence*, within a team that has not yet developed its group culture.

SETUP

“In my mind’s eye, Horatio”

Building material

Building material should allow multiple concepts and not only geometrical variations over a single concept. Two concepts easy to implement are ‘piston-’, and ‘bellows-pumps’. Piston-pumps are easy to build from balls of Styrofoam and cardboard cores from rolls of disposable paper sponge-towels (choose balls that are undersized with respect to the ID of the rolls). Bellows-pumps are easy to make from large coffee paper-cups and 2 litres freezer plastic-bags (have ‘small’, ‘medium’, and ‘large’ paper-cups for geometrical variations).

Allow for variations in size by making available raw sheets of thin (cheap) ‘artist’s cardboard’ that can be cut to shape and size; coffee cups becoming the ‘piston’. Long wooden stir-sticks will make handles and rods once assembled in bundles. Cores of sponge-towels rolls will find their way as handles and rods for the bigger piston-pumps. For bellows-pumps, think not the design will restrict itself to a freezer bag caught between two coffee cups: stir-sticks become as good stiffening ribs as imaginative cuts of raw cardboard sheets do.

All this creativity being saved by... duct-tape. Make it an expensive item at the store. It is difficult to sell duct-tape by the yard. Buy small 7-meter reels at the general store; use a balance from the chemistry-lab that can measure to the 1/100 g; sell full reels of tape; have the teams cost their pump by weighing the tape used to the fraction of a gram. Duct-tape weighs approximately 8.6 g/m. Get statistics from single source supplies, and always use the same balance. It does not matter if they cheat; just keep in mind to talk about bankruptcy and repercussions on retirement funds, when a corporation gets its success from hiding its true costs to itself or to the stockholders.



Figure 1. Basic material, and many rolls of duct-tape to save the day

Not too fancy testing apparatuses

Call it 'pressure test' — Make water-column manometers from plywood, tygon-tubing and a plastic ruler (tilt them to an angle for the pumps that cannot deliver any pressure, so students will nevertheless witness some visual repercussion). All the piston-pumps being leaky, define 'success' by water height & time: "holding 10 cm of water for 6 sec." Beware of squirts, and run the output of the manometer spout into an overflow bottle. "What are we testing exactly?" warrants being part of the reflection phase.

Call it 'volume-test' — Materialise fixed volumes from empty boxes of photocopy-paper. Fill about two-thirds of the box with books about hand-pumps, and put a plastic garbage-bag in the remaining cavity. Tape the opening of the garbage bag around a 30 cm length of tygon-tubing (prepare many bags this way, to just switch bags between teams). Define 'volume filled' as the state of the bag that will just begin to lift a piece of light cardboard laid across the top of the opened box. Teams keep track of the 'time to inflate'.

Call it 'flow-test' — Have rows of 9 to 16 candles ready to be blown. This is a most popular test, so make matches handy. Keep this an open-air test, at the mercy or cross-flows from the air conditioning and all. Then, of course: "What are we testing exactly?"

All tests suffer from uncontrollable extraneous factors, and leaks develop in two test beds. The stage is set for a fruitful discussion about the pitfalls of writing down "test" in a specification, rather than investing time and effort to think of some set of quantitative criteria.

Teams and Coaching

As in the 'Skyscraper' DBT exercise, teams of four to five form at random (seven is a crowd). A ratio of ~60 participants for three to four instructors satisfies peaks. It is best for two of the instructors to know the exercise in depth, the other(s) having received only a short set of rules or being mid-curriculum students that have participated in the past.

Adjust the coaching style to your goals. 'Design' may or may not be the primary one.

DBT room setup

It is wise to distribute the instruction sheets after a short introductory talk. Save your work surfaces: do not distribute X-acto knives ahead of time. Do so one by one, insisting that only light 'in-hands' cutting is done at the tables. Have scissors for every table. Save your methodology: only have secondary school geometry kits and drawing sheets ready at the tables. The rest is a source of distraction.

As shown in Figure 2, the ‘Store’ should have displays where participants can come and look at the material (think of it as a catalogue). Exploration by handling and getting the feel for hardness, rigidity, resistance to tears, etc. requires the purchasing of the wanted material. Have trays ready (the tops of the photocopy-paper boxes). ‘Purchasing agents’ all come in a very short time span and the store needs good organisation. Have two cutting stations ready at the store, to handle all cutting done by resting the knives on a surface.



Figure 2. Work and ‘stockroom’ tables for a group of 50 split in 10 teams of five.

“By indirections find directions out”

Set the goals as you would functional specifications. Avoid text, and use a table to present principal and complementary functionalities, and constraints. Use some equation to compute the ‘merits’ of the different pumps. Something like:

$$P V = n R T \quad (1)$$

is a nice one to start with, without considering costs, where:

- P price you are willing to pay for the pump,
- n number of candles blown in the line-up,
- R height of water column maintained for t sec
- V volume inflated,
- T time to inflate volume V .

Once experienced, change the equation by removing the budget limit, and making *cost* one of the parameters in the equation. Let the teams decide the design they should favour to optimise ‘merits’ with cost included. (Then discuss ‘risk aversion’ and the psychology of engineers; hesitations or discomfort, effects of problem “framing” in relation to the position of people in the Kolb quadrants of experiential learning or to the Myers-Briggs indicators.)

A criterion easy to set, that rules out some of the detailed designs and none of the concepts, is *volume displaced per stroke*: it can be that cores of sponge-towel rolls satisfy the volume limit at full length, but not the *volume displaced* with a piston inside. Make economic use of these ‘traps’ with groups of less than 20 teams, as students oversee them easily. ‘Traps’ make the need to analyse very relevant though.

A sound suggestion is often to “get out of one’s office, and go see on the shop floor or in the field.” Have many sizes of tygon-tubing at the store, as an opportunity to put the good word to work. Make connections to two of the test beds by tight-fit insertion of tygon-tubing of matching ID/OD. Let the teams *get out of their office*, and find by themselves what size they should buy. Put many ID/OD on display, and deliver at random when teams do not specify ID or OD sizes on their purchasing list.

The enthusiasm at the 'volume test' tends to age the pumps quickly. The result of the 'pressure test' may consequently depend on testing sequence. Rule this out by imposing a sequence, or let the teams decide what sequence they should use to maximise their gains.

Do not exaggerate with this spirit of 'indirections'. Teams are finding their way through enough confusion as it is. You may consider it sufficient for them to have thought about the question. Decide whether answers are 'free' or, as for a consultant, provided for a charge.

RESULTS

Students responded well and involved themselves genuinely in both 'Air pump 1' and '2', as a Conceive-Design-Implement-Operate compact exercise (see Figure 3 and Table 1).



Figure 3. Conceive - Design - Implement - Operate the 'Air pump'

"I must be cruel, only to be kind"

The students did not appreciate the necessity of analysis first hand. They did not readily see the merits of producing sketches of their concept(s) either. The second may lead to the first: mechanical analysis often rests on a good visual model, and appreciation of the phenomena present; bad graphical representations of a situation often result in poor analysis.

To allow the purchasing of building material without a proper sketch of the concept(s) at hand is to pave the way to chaos, or at least for the team budget to go astray. Building results in makeshift improvisation with little future into it. To request an R & D plan for the purchasing of R & D material is for you to decide: too many rules and too much structure sometimes impede the initial 'spark' of actually trying. In our view, it is preferable for 'something' actually to happen for discussion to build on, although we fully realise it may result in technical failure.

The choice to make depends on your goals, and may well be different for 'Air pump 2' (within a project module) than it is for 'Air pump 1' (Orientation week).

It was a pump; "take it for all in all"

Technical requirements already overwhelm the teams. Think twice before imposing complementary functions like 'To be aesthetically pleasing'. Stick to technical functions unless the teams incorporate students from a commercial design school or faculty.

We know it is difficult to deal with non-technical complementary functions like aesthetics in a design, when firstly trained only with technical criteria. Think of your bookcase as a student however: it started with 12 bricks and 3 wooden planks, and only later did it become Poul Hundevad's 'HU' bookcase cabinet in rosewood veneer. Begin with the 'bricks' and 'planks'.

Yet "... know a hawk from a handsaw."

Depending on your tolerance, choose the extent to which you announce what are 'Aye-pumps' and what are 'Nay-pumps'. Do not trust the student's implicit assumptions will be your own: write them down.

It is surprising how creativity compares between 'designing a pump' and 'bending natural assumptions'. Be ready for everything and anything, and realise ahead of time students have great difficulties in knowing how to fit implicit assumptions when given functional requirements: they think in terms of 'solutions'.

"Do you think I am easier to be played on than a pipe?"

A very popular natural design is the 'valve less ten-fingers-two-mates-operated-pump': as one member of the team actuates the strokes, another is supposed to rest his fingers on intake holes and pinch some restriction to the nozzle, all with appropriate synchronisation and synchronicity. A free entertainment no professor can forget.

The constraint "Operated by a single individual" usually takes care of the matter. Yet, ...

"... let the candied tongue lick absurd 'pumps'"

The design that then becomes popular is the 'bagpipe-pump'. One or two pieces of tygon-tubing and a freezer-bag will do it. The single orifice 'pump' has to be repeatedly connected and disconnected to its point of use. When disconnected, the operator puts the nozzle into his mouth and blows into the bag. He then plugs the nozzle with his thumb. The tricky part is to reconnect the nozzle to the point of use ..., so maybe you just hold it close. Then fit the bag under your armpit, and press with your upper arm while your hands are busy with the nozzle and the connecting intake of the apparatus. Did you not know that makes a pump?

A constraint like "... maintaining connection" usually closes the gap in the rules. When present, the 'volume-test' also winnows the wheat, separating the good grain from the chaff: not maintaining the connection considerably lengthening the time to inflate.

***"Our wills and fates do so contrary run
That our devices still are overthrown"***

The test beds develop leaks. They develop on manometers of the 'pressure-test' when quick disconnect couplings are handled to reset the volume of water to its initial value after a pressure surge has caused the water to squirt into the safety bottle. They develop at the seam between the bag and the tygon-tubing of the 'volume-test' when students press the bag too firmly to empty it. These weaknesses did not cause strong discontent.

Table 1.
Summary of results for Orientation week and First project module

CDIO-R	First day of Orientation week (Semester 1)	First day of 1 st Project module (Semester 2)
General purpose	Have new students create bonds; create a base to present curriculum	Create a common base to present the module, and to reference to thereafter
Mode	Playful challenge	Criteria based DBT
Teams	Forced randomness across groups (3 gr. of 60) and teams (4 to 6 per team)	Determined by group schedule (3 gr. of 55), spontaneous team (~5 per team)
Tests (intent)	Number n of blown candles in line, Height h of water maintained for T sec, Time t to inflate bag of volume V cm ³	Number n of blown candles in line, Height h of water maintained for T sec, Time t to inflate bag of volume V cm ³
Tests (truth...)	Other activities of Orientation week cause the curtailment of full testing	Often have to curtail; Too long to inflate 10,000~15,000 cc; Candle blowing and Water column trigger much interest
Prior attitude	Relaxed, Perplexed, Happy to mix, and to have a hands-on exercise	Expectant (students now know ahead of time); May arrive prepared (may be beneficial to force random teams again)
Ice-breaker	Yes, Structured	No, Left to the initiative of the team
Initial material conditions	Instructions and geometric drawing kits on tables; Cutting tools distributed with verbal reminder of written precautions	Tools on tables (no expenditures); Material as visual display only; Think of safety glasses
Some possibilities and constraints	Roaming mentors ask for (and help do) sketching; Material supplied as per itemised list ("open bar", keep track of usages); Hints peppered around	R/D purchases possible; Must produce & document concept before purchasing material to build; Material supplied as per "purchasing list" (no real BOM)
<u>C</u>onceive (<i>They have learned!</i>)	Long silent hesitations; Frequent visits to material 'stock-room'; Usually retain first idea; Team easily follows any idea voiced with conviction; Little if any purchases for R/D exploration; All teams take about the same time $\pm 20\%$	(15 min) Discussions start in 1 min; Compare different prior experiences; Poor writing in log book but various rough sketches on separate sheets; Strong feelings about feasibility; Some teams take twice the time of others
<u>D</u>esign (<i>They have not learned that much!</i>)	No real design nor analysis; No usage of cut views given, showing valves for single and double stroke air pumps (ignorant about the relevancy of hints)	(25 min) Some deepening of concepts; No analysis (at most compute volume of cylinder); No track of thoughts about leaks; Some concerns about valves
<u>I</u>mplement (<i>They have not learned at all!</i>)	Wide variations from team to team (gender, cultural,...); Makeshift job (decide as you go); Very little task distribution / parallelism; Enthusiasm	(25 min) Wide variations from team to team (gender, cultural,...); Makeshift job (decide along); Little task distribution / parallelism; Enthusiasm; Will skip break
<u>O</u>perate (test)	Expectant; Interests all team mates; Discussion with standing professor ^(a) ;	(2 × 10 min + 10 min break between runs) Expectant; Interests all; Desire to redesign; Skip break; Should age pump by 100 strokes during break (not done)
<u>R</u>eflect	None asked	(30 min) Self & in group (participate verbally: 1/8, non verbally: 1/4, 'pump in hand': 1/8); Finish at home (no marks)
Follow up (on Reflect)	Satisfaction survey: ~85% (not about the quality of design, of design process or of teamwork)	From individual log books, sample of ~25 over ~150 (see Table 2)

A permanent assembly will solve leaks at the manometers, allowing for its replenishment from the opening to the safety bottle. Making a number of bags ready so all can be deflated slowly will easily solve leaks at the bags. The blowing of candles do not present surprises nor weaknesses; the students find it impressive, and take pleasure in blowing as many as they can (even lining-up multiple rows into a single one) should the pump survive the test or not.

Nothing “is rotten in the state of Denmark”

Persevere. You will witness major technical improvements in ‘Air pump 2’ from ‘Air pump 1’. As the news spreads about ‘Air pump 2’, students actually prepare for it. Impose the random formation of teams to avoid students neatly producing designs beforehand.

There is no reduction of interest. Free-style surveys include positive or no comments at all about the ‘Air pump’, and no negative comments. The absence of negative remarks is significant in itself, as other exercises do get negative comments from some students.

An on-hours individual, written reflection closes the exercise (no marks, nor prompts about topics to reflect on). All logbooks were globally evaluated four to nine weeks after ‘Air pump 2’. The first, second and third quartile boundaries were computed. The written on-hours reflection about ‘Air pump 2’ was examined in detail on three 4% samples of logbooks, each taken from the vicinity of quartile boundaries. Table 2 shows compact free translations (not verbatim) statements from this 12% sample, mostly from the first and second quartile boundaries. Students around the third quartile were satisfied with descriptions rather than reflections. An ‘off-hours’ reflection exercise was not so successful, except for a few students. The technical performance of the pump had little impact on the quality of the reflection.

In one group, the instructors misinterpreted the goals of the reflective phase. They revealed a numbered list of prompts beforehand. A sample of 15 log-books again taken in the vicinities of the three quartile boundaries then shows the vast majority of comments to be strictly descriptive, and the students to be satisfied by ‘ticking the list’ instead of thinking and making links. Tipping off students seems to have an adverse effect on the quality of the reflection.

***“Find out the cause of this effect,
Or rather say, the cause of this defect,
For this effect defective comes by cause.”***

“Alas, poor Yorick!”

On Orientation week, ‘Air pump 1’ only have 10% to 15% of the pumps with attempted tilting disk valves, the majority being ‘piston pumps’ (see Figure 4). As semesters pass, First project module pumps have had about the same, then an increase in (unsuccessful) attempts to assemble complicated ball check-valves (see Figure 5) with ‘piston pumps’, and —recently— an abrupt change of popularity towards ‘bellows pumps’ with or without valves. Hallway discussions probably fuel these bulk trends, as there is nothing more public than a secret inside a classroom. It remains that students seem unable to appreciate the meaning of ‘airproofness’ in practical terms.

Some instructors suggest the failure to be “catalectic” in nature: students would simply not have experienced with one-way valves, and be strangers to the concept. They suggest the introduction of a visual apparatus with flipper-gates and rolling marbles the students could tilt back and forth. In their view, watching the marbles go from A, passing the gate to B, and then passing the second gate to C, will have the students grasp a missing concept. The students would then transfer the concept to pumps, where molecules replace marbles.

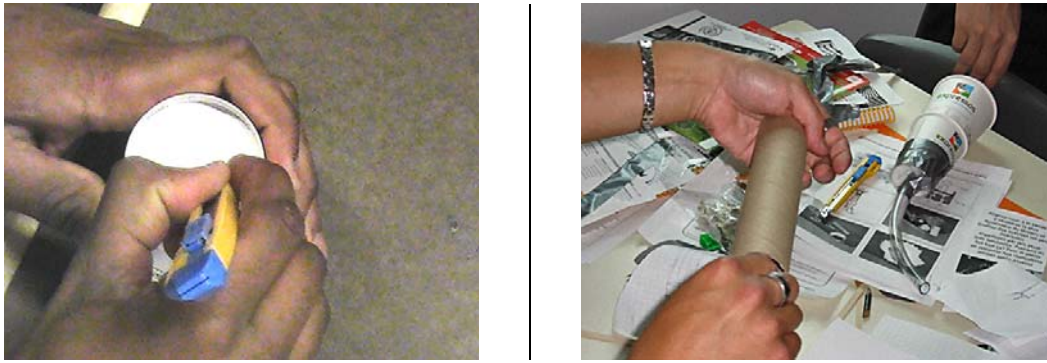


Figure 4. First generation attempts at making one-way tilting disk valves



Figure 5. Second generation attempts at making ball check-valves

We tend to believe the concept does not pose problems. We speculate that the undisciplined nature and the unwillingness of a physical apparatus to behave the way it “should” has itself become a mere concept, and is practically strange to them. Introductory science courses used to mark the end of magical thoughts. However, the tendency to replace physical benches with simulators might now fuel them. Students could grasp the simulated concepts and nothing more, nothing that — by unplanned chance — might have been conveyed by the physical nature of the bench. When interpreting a ‘real world situation’, maybe it simply does not cross their mind that a pressure drop increases as a restriction lengthens (unless this was specifically simulated), that poor joints become reasonable ones given enough overlap. Students seem to hope molecules will not circumvent a Styrofoam ball resting on a hole cut by hand in the bottom of a paper cup. Trying to breathe through a thin straw might be a better initiation to reality, than having marbles roll past a flipper-gate.

*“(Do) We go to gain a little patch of ground,
That hath in it no profit but the name(?)”*

As much from the free-style surveys about the exercises as from the samples from the log-books, students appear to find enough benefits from the ‘Air pump’ not to report discontent nor suggestions about technical improvements. The current quality and quantity of reflections do not seem to correlate with pumps actually functioning the way pumps should.

It may be appropriate to question our desire to see (say) 30% to 40% of the constructions actually be classical pumps, with intake and outtake valves. Are students not wiser in taking the exercise in a more global perspective, and in finding benefits and intellectual nourishment outside of the realm of technically sound pumps? Just what additional benefits must one secure from a single exercise, once it has delivered advantages in all the contents of Table 2?

Table 2.
Sampled testimonies (12%) from individual on-hours reflection exercise (no prompts)

<p><i>"I should take care in following guidelines. I don't take enough time to develop my ideas, to really understand before I go into action."</i></p> <p><i>"I should trust a decision when it was carefully made by the group, not jam the brakes."</i></p> <p><i>"Had we built on the contributions of all, we would have had an advantage in optimisation."</i></p>
<p><i>"We didn't respect the constraints (difficult)."</i> [Unspecified difficulty: is it in 'respecting' or is it the 'constraints' given on the instruction sheet?]^(a)</p> <p><i>"We really need to make use of everyone's ideas, to discuss, to refer to criteria (anticipate advantages and disadvantages) for the thing to go <u>forward</u>."</i></p> <p><i>"What could have we done to foresee technical conclusions (max-min, friction, jamming)"</i></p>
<p><i>"Too obsessed by 'piling-up stuff'; take more time to imagine / create => cohesion."</i></p> <p><i>"Good to retain the simplest idea after all is said and thought."</i></p> <p><i>"We discovered potential improvements after building... nothing left on budget by then."</i></p>
<p><i>"Brainstorm."</i> <i>"Distribute tasks."</i> <i>"Make a better job at designing."</i> [Triple underline for last]</p>
<p>[Task distribution: only descriptive, no conclusion. Followed by text under.]</p> <p><i>"Our analysis was so weak, inexistent. We relied on past experience though. But we went for the detailed design too soon, without an idea of what we were going for."</i></p> <p><i>"Why were we so inefficient? What to do and how to do, to avoid such inefficiencies?"^(b)</i></p>
<p><i>"That design was not efficient. Needed technical modifications (the valves are critical)."^(c)</i></p> <p><i>"It would have been important to define the steps we went through to avoid confusion."</i></p>
<p><i>"Learn how to sketch. Sketching is the best way to communicate your ideas."</i></p> <p><i>"Design – Take time, foresee repercussions before you build."</i></p> <p><i>"Tasks – Share. It's important."</i></p>
<p><i>"My contribution was dispersed around. We broke into sub-groups without coordination."</i></p> <p><i>"When it has to work, 'technical consensus' ≠ 'democratic voting': got to be systematic."^(d)</i></p>
<p>[ONE (1) student in 150, but mostly after seeing the late prompts]</p> <p><i>"We haven't been honest / ethical in our tests and calculations (pretending). It wasn't planned dishonesty, just 'happened'. Not 'OK' nevertheless."</i></p> <p><i>"I tried to share and assign jobs, but was overcome by another wanting to lead."</i></p> <p><i>"Sure, there were some isolated ideas that took us forward. But the bulk of the thrust came from sharing ideas. That, we could do thanks to different prior experiences."</i></p> <p><i>"From the start, we lined-up all the ideas from the prior experiences. Could then choose more easily. I analysed some of the suggestions, and found not all had been foreseen."</i></p> <p><i>"I acted positively, but I did not encourage anyone. Took too much time to control time."</i></p> <p><i>"I didn't do something from A to Z. Jumping around. So was everybody. In the future, we must assign jobs and keep members accountable. That should help efficiency."</i></p> <p><i>"I suggested ideas based on first-principles. Not all were good, but we could tell why."</i></p> <p><i>"We took risks without checking: a plastic bag ages rapidly. Explore with facts." [etc.]</i></p> <p>[Above is roughly half of what was reflected individually, <u>after</u> seeing the prompts. About the same content as other students <u>before</u> seeing the prompts. Only approx. 10% of students somewhat deepened their reflection after seeing the prompts.]</p>

- (a) Author's comments in brackets within the cells of Table 2.
- (b) Same student would repeatedly 'admit being at fault' in exercises where he was asked to 'give feedback' to teammates.
- (c) At every 'Air pump 1', the vast majority of pumps do not have one-way valves. At 'Air pump 2', ~30% of teams try to 'negotiate' for valve less "inflatable bag-pipes".
- (d) Shows the confusion that can arise after being instructed on 'transferable skills'.

CONCLUSION

This paper presented a new DBT exercise better aligned with the discipline of Mechanical Engineering. Orientation week and the first project module of the curriculum make use of it. Inexpensive building material easily accommodates the two concepts of piston- and bellows-pumps, with a wide variety of sizes and shapes. Testing apparatuses must be prepared in advance, and the results of the three tests (flow, pressure, and volume), either single or statistical, can determine “performance” by the use of a compounding equation. Results over four semesters show the same technical weaknesses in prior knowledge from the part of the students. The percentage of pumps that perform well enough over all three tests is half of what was hoped. Nevertheless, not only is there no strong sign of adverse effects on the motivation or willingness of students to carry out the assignment, but undirected individual reflection appear to harvest all that would be expected of a DBT exercise.

ACKNOWLEDGEMENT

"Beggars that I am, I am [not] poor in thanks."

All my appreciation to the now retired prof. Bernard Sanschagrín, who modified his course to allow my introduction of ‘Air pump 2’, and who supported many of my other initiatives. Thank you also to prof. Eduardo Ruiz who embraced the idea and adapted his material. May Mrs Danielle Lemay accept my gratefulness for the 14 “Orientation days” she never failed us. My thanks also go to the professors and assistants who regularly help in organising ‘Air pump 1’, and who stand prepared at the nine test stations, to encourage and coach the new students.

"The rest is silence." (William Shakespeare, Hamlet 5.2)

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ACTIVE LEARNING IN LARGE CLASSES

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ABSTRACT

In this paper we present our ideas of how to use active learning in the lectures when teaching large classes (more than 50 students), and describe how we successfully have in a second semester course in the Bachelor of Engineering (BEng) and Bachelor of Science Engineering (BSc Eng) program at the Technical University of Denmark (DTU). Approximately 200 students is attending the lectures in the course.

The main idea is to use inductive, case-based learning, with many small exercises/discussions during the lectures. We describe a framework for the lectures, that most lectures in the class were based on. The framework contains the conceive, design, and implement stage from the CDIO principle.

KEYWORDS

large classes, active learning, lectures, inductive teaching.

INTRODUCTION

When giving lectures it is necessary to keep the students active. This improves the students learning outcomes. As it says in Standard 8 of the CDIO standards, active learning in lecture-based courses engage the students and can include methods such as small group discussions. It is our experience, that many lecturers find it difficult to implement active learning in large classes (classes containing more than 50 students). We give a description of how this can be implemented, and a way to structure the lectures using active learning and inductive teaching. The use of inductive teaching and active learning is of course not new. What we try to convey here is how to use it in lectures for large classes. We also give a concrete way to structure the lectures, that incorporate both inductive teaching and active learning.

CONCEPTS

In this section we describe our ideas. In the first subsection we describe how we get the students to actively take part in the lectures. The second subsection contains our framework for the lectures.

Active Students

To keep the students active during lectures, they are given small exercises that they can solve either by themselves or together with the students sitting next to them. They are given 5-10 minutes to solve the exercises, and then their solutions and ideas are discussed in plenum. The motivation for this is

- It forces the students to think and get in touch with the material during the lectures. For example, the students appreciate a solution more if they have tried to solve the problem by themselves first.
- It gives the students time to get some understanding of the material before we proceed. E.g, if two new concepts/definitions are going to be compared in the lecture, the lecturer can ensure that the students really understand both definitions before they are compared. Another example is to let the students try to run an algorithm on an example before analysing it.
- It gives the lecturer a chance to see what the students find easy/difficult during the lecture, and thereby an opportunity to adjust during the lecture.
- When the students are allowed to talk to each other and solve the exercises together, they are more inclined to answer/participate in the discussion afterwards (this can otherwise be a big difficulty in large classes).

Structure of Lectures

We have developed the following framework that the lectures are build around:

1. **Lecturer:** Introduction to the problem
2. **Exercise:** Try to solve an example instance of the problem (and try to come up with a general method/algorithm to solve the problem that works on all possible instances).
3. **Discussion:** Discussion of the students solutions and ideas.
4. **Lecturer:** Explain solution/algorithm + give an example.
5. **Exercise:** Run the algorithm/use the method on a new example.
6. **Lecturer:** Guide to analysis of the method/algorithm (leading questions).
7. **Exercise:** Show/find properties of the method/algorithm.
8. **Lecturer:** Put together the properties of a proof.

It is a mix of standard lectures and exercises. The exercises/small group discussions are progressing during the lecture. Starting with small examples and ending with questions that lead to a mathematical proof. In the last exercise (7.) the students are given questions in an order that also show how to build up a mathematical proof.

PROOF OF CONCEPT

In this section we describe how we have used this concept in a large class at DTU for the last 3 years.

Background

The class of study is a 2nd semester introductory algorithms course at DTU. Students from many different study lines participate in the course, but it is mandatory for BEng students in "IT" and BSc Eng students in "IT and Communication Technology" and "Software Technology". The teaching consisted of 1 1/2 hours of lectures followed by 2 hours of exercise classes in smaller groups/classes (around 30 students in each exercise class). Approximately 200 students are attending the lectures. Since the students come from many different study lines, they have very different prerequisites.

Evaluation

The described lecture form has been used for 3 years now at the course, and the students are very positive. In the midway evaluation the students were asked whether they thought that the small exercises were helping them to understand the material covered at the lecture. This year 76% answered to a high or very high degree. If we look at the results for all 3 years between 57-76% answered to a high or very high degree, and only around 1-4% didn't think they helped at all.

SESSION AT THE CONFERENCE

In the freestyle session at the conference, we will give a concrete example of a lecture from the course. The example will be from the first lecture in the course, and does not require any previous knowledge about algorithms.

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QUALITY ASSURANCE WITH CDIO SELF-EVALUATION - FIRST RESULTS OF A NORDIC PROJECT

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ABSTRACT

This paper describes the Nordic project 'Quality Assurance in Higher Education'. The main goal of the project is to develop and implement a self-evaluation model in the participating Higher Education Institutions (HEIs) to support their quality assurance work and continuous curriculum development in the field of engineering. Furthermore, the project aims at developing cross-evaluation methods for international use as well as strengthening the cooperation of HEIs in quality assurance and disseminating good practices of QA. The framework of development in this project is based on the CDIO initiative and the CDIO self-evaluation model. The project started in October 2009 and will continue until the end of October 2011. The project is divided into two phases. The first phase focused on self-evaluation and the second will focus on cross-evaluation. This paper describes the first project phase. The main results are a detailed definition of the self-evaluation process, well-documented self-evaluations of the participating degree programmes, as well as identification of main development areas and actions in each participating degree programme. The development actions included, for example, a) implementing a capstone project into the curriculum, b) practical training – improving the connection between the industry and a HEI, c) integration of teaching activities – CDIO awareness, and d) programme organization – programme management team including student representatives. Furthermore, the project has increased the partners' understanding of other partners and their challenges. Finally, the quality assurance has been enhanced in each participating programme. Hopefully, this project will provide new ideas and support for quality assurance work on other higher education institutes.

KEYWORDS

Quality Assurance, Self-evaluation, Nordic project, Continuous development, Programme development

INTRODUCTION

The overall idea of CDIO initiative is to support engineering education development and educate students who are able to [1]:

- master a deeper working knowledge of technical fundamentals
- lead in the creation and operation of new products, processes and systems
- understand the importance and strategic impact of research and technical development on society.

Important tools in this task are the 12 CDIO standards [2] and CDIO syllabus. The standards act as guiding principles for designing and development of a degree programme. Focusing the development in the areas defined by the standards will lead to better student experience and improved learning results. The standards address issues relating to what to teach and how to teach, but also issues relating to teaching staff skills. Finally, the 12th standard focuses on evaluating the current situation of the programme. This is the fundamental starting point of the Quality Assurance in Higher Education Institutes (QA in HEI) project described in this paper.

QA IN HEI PROJECT

The QA in HEI project is funded by Nordplus [3]. The project started in October 2009 and will continue until the end of October 2011. The project has four partners: Turku University of Applied Sciences (TUAS) is the coordinator, and Royal Institute of Technology, Technical University of Denmark and Helsinki Metropolia University of Applied Sciences are other partners.

The main goal of the project is to develop and implement a self-evaluation model in the participating higher education institutions in order to support their quality assurance and continuous curriculum development in the field of engineering. The project aims at defining the self-evaluation process in HEIs and developing new tools for supporting the process of quality assurance. Based on these newly developed methods, the quality of education is monitored and actively improved in HEIs. Furthermore, the project aims at developing cross-evaluation methods for international use.

The project has as an objective the construction of a framework for quality assurance that promotes the international comparability of educational quality. The quality assurance models are established, implemented and further developed in the participating degree programmes. The main purpose of this international cross-evaluation model is to provide the HEIs with new methods and tools of international quality assurance work in close co-operation with other HEIs. The cross-evaluation between HEIs promotes both the quality assurance work and the quality of education. Thus, the project aims at creating a circle of continuous quality assurance that fosters active development culture. In this cyclic model, the quality of education is reviewed by using self-evaluation and cross-evaluation methods. Based on the evaluation results, the development actions are defined, planned, and implemented in order to promote educational quality.

In the Nordic level, the project also aims at strengthening the co-operation of HEIs and disseminating the best practices of quality assurance methods and educational solutions. The international cross-evaluation model, by definition, promotes cooperation and comparability of educational quality in the Nordic and international level.

The project is divided in two phases that have different focuses. The first phase focused on the self-evaluation and it contained the following steps:

- 1) Definition of the self-evaluation process
- 2) Conducting the self-evaluation in the selected degree programmes
- 3) Analysing the results of the self-evaluation and defining development activities
- 4) Assessment of self-evaluation criteria and process based on the gained experiences.

The second phase, currently ongoing, focuses on cross-evaluation. Therefore this paper focuses on describing the first phase of the project.

Each project partner has a core group of persons working in the project. Typically these persons included the local CDIO leader, a quality assurance expert and degree programme manager/leader. In addition, each HEI defined a degree programme that would pilot the developed self-evaluation model and participate in the cross-evaluations in the second project period. A working group of local players followed the self-evaluation model and produced defined documentations. Finally, the project has a steering group formed by the local CDIO leaders.

DEVELOPED MODEL AND GUIDELINES

At the beginning of the project, the three main steps of the self-evaluation process were defined:

1. Create a programme description
2. Perform the self-evaluation
3. Define possible development actions.

The programme description should contain the following topics:

- Introduction
- Description of the programme goals and structure
- Description of the curriculum and courses
- Description of selected themes
 - Introduction to higher education study and to engineering
 - Training of engineering competences
 - Thesis work
 - Engineering workspaces
 - Student – work life connection
- Description of continuous development process

The description should be specific enough to allow the evaluation of the programme. We agreed to base the evaluation mainly on existing, functioning documentation in order to minimize the production of descriptions that serve only the purpose of this evaluation. If the evaluation inspires improvements in the “real” documents, it may also contribute more directly to developing the programme. The evaluation guidelines included several supporting questions to help producing the programme description.

The self-evaluation is based on the programme description. It contains the actual ratings of the programme in relation to the CDIO standards and recommendations for identified improvements. We grouped the CDIO standards to clarify the structure of the self-evaluations:

- Criterion A. Programme goals and design
 - Standard 1 – The Context
 - Standard 2 – Learning Outcomes
 - Standard 3 -- Integrated Curriculum
- Criterion B. Course goals and design
 - Standard 4 -- Introduction to Engineering

- Standard 7 -- Integrated Learning Experiences
- Standard 8 -- Active Learning
- Standard 11 -- Learning Assessment
- Criterion C. Selected themes
 - Standard 5 -- Design-Implement Experiences
 - Standard 6 -- Engineering Workspaces
- Criterion D. Continuous development
 - Standard 9 -- Enhancement of Faculty Skills Competence
 - Standard 10 -- Enhancement of Faculty Teaching Competence
 - Standard 11 -- Learning Assessment
 - Standard 12 -- Programme Evaluation

The outcome of the self-evaluation should contain the self-evaluation report, a description of three best practices identified by the programme, and a description of the local implementation of the self-evaluation process. Possible development actions are defined, documented and scheduled based on the self-evaluation. They are summarized in an action plan showing the defined and scheduled development actions.

SELF-EVALUATION PROCESSES AND RESULTS

All project partners have been dedicated to the project goals: self-evaluation has been conducted in the selected degree programmes. Based on the results of self-evaluation, development activities have been suggested and discussed together.

Case Turku

The Degree Programme in Information Technology has during the past few years participated in several different evaluation processes. The programme participated in an internal cross-evaluation process at TUAS in 2007, and the different phases of the planning, implementation, evaluation and improvement processes of the programme were studied. In addition, the programme was a candidate for a national centre of excellence in education for 2010-2012, and the application process included an extensive self-evaluation process. Moreover, The Finnish Higher Education Evaluation Council audited the quality assurance system of TUAS in autumn 2009, and the programme participated actively in the collection of audit data, too.

All these recent evaluation processes involved the faculty and programme management, teachers and students. Thus, this CDIO self-evaluation process was based mainly on the existing materials and experiences gathered during the previous exercises, complemented with CDIO specific parts, and a student survey conducted by a student representative in the QA in HEI project.

The self-evaluation process provided again an opportunity to reflect the processes and operations of the programme from different perspectives, especially focusing on the topics emphasized by the CDIO initiative. Topics currently present in the continuous development process of the programme were discussed also during this self-evaluation. For example, defining and improving the programme and course level learning objectives has been one of the main areas of improvement during the past two years. Currently, this process focuses on defining and improving assessment criteria – there definitely still is much to do on that field. In addition to these ongoing development actions, four specific improvement items were identified during this self-evaluation:

- **CDIO Capstone Project:** The current curriculum is flexible and encourages students to participate in different types of projects especially during the second half of their studies. However, these projects are not a mandatory part of the curriculum, and

furthermore the projects are often started on an ad-hoc basis. That is, the curriculum will be studied and a CDIO Capstone project included into it as a more integral part than before.

- **International elements:** In addition to this programme, our faculty also has a fully international Degree Programme in Information Technology. These two programmes have a long tradition of co-operation (shared facilities, joint courses and teachers etc.). However, the co-operation (especially from the students' perspective) is focused on the latter part of the studies. That is, more could be done together already in the beginning of the studies. This could improve the internationalization and networking skills of the Finnish students and, moreover, make it easier for the foreign degree students to integrate in the Finnish student community.
- **Practical training:** The curriculum contains a mandatory practical training worth 30 ECTS credits. During the evaluation process it was identified that the learning objectives and, especially, the assessment of the practical training course need to be updated and improved.
- **CDIO awareness:** Already for some years now, the programme has been developed according to the goals set by CDIO standards. However, the awareness concerning CDIO and its elements is not on a very high level, especially among students. Thus, actions to improve this will be planned and implemented.

Case KTH

In KTH the Chemical Engineering programme from the School of Chemical Science and Engineering participated to the QA in HEI project. The programme is not a fully fledged CDIO programme yet, but it is inspired by the CDIO initiative and has informally adopted many CDIO ideas over the years. So far, the main focus of the programme has been on the integration of communication skills. Last year, KTH has decided to proceed and implement CDIO in all programmes, and now more coherent plans are being formed for each programme, including this one.

The self-evaluation process of the three-year Bachelor programme in Chemical Engineering focused on creating a programme description. The actual CDIO evaluation and rating have not been done yet. The programme description will be used, firstly, in teacher meetings and, secondly, for the actual evaluation and rating. The self-evaluation process itself was very time-consuming work. This should be discussed and possible changes to the guidelines should be considered.

The programme description is well done and there should be possibilities for taking advantage of it. For example, based on the self-evaluation, the Chemical Engineering programme identified several strengths and weaknesses concerning the programme. The major findings regarding potential development actions are the following:

- **Programme organization – programme management team including student representatives:** The student representatives for Chemical Engineering programme should be included in the programme management. So far the role of the representatives has been slightly unclear.
- **New funding systems – reflections to quality?**
- **International aspects:** the programme is intended to prepare students for advanced studies and as part of that, the students should be required to learn adequate technical English.

Case DTU

The self-evaluation process of the Bachelor of Engineering programme in Chemical and Biochemical Engineering at DTU was conducted somewhat differently from the other

programmes involved in this project. After having been introduced to the project and its aims by the local Nordplus project coordinator, the director of studies formed an evaluation group consisting of two teachers, two students and himself. This group collected the data for the self-evaluation report by looking through the official documents (the syllabus etc.) and by talking to fellow teachers and students in order to include their opinions and experiences. They then wrote the self-evaluation report in close collaboration and subsequently discussed the report in the department board of studies.

In order to take the self-evaluation a step further, the report and the findings were discussed at an evaluation meeting at DTU with the participation of all directors of studies and the dean of studies. The purpose of this meeting was to share the findings with director of study colleagues and to identify and discuss actions for improvements of the programme in question as well as study programmes at DTU in general. Since many programmes face the same challenges, this meeting seemed valuable to all the participants and some more general conclusions were drawn. The most important of these was the creation of so called helicopter documents showing the ideas behind the study programme and describing the structure and progression of the programme. In other words, it is a detailed description of all the details which are not covered in the official programme documents. The content of this document should be well known to all teachers in the programme and it should be revised regularly in order to reflect the actual situation at any given time.

In the light of the various discussions of the self-evaluation report, the director of studies and the local project coordinator drafted a document containing several development areas. So far only a few of these areas have been addressed but more will be addressed in relation to and in the wake of the peer evaluation process with KTH, which has not yet been carried out.

The self-evaluation of the BEng in Chemical and Biochemical Engineering identified several strengths and weaknesses concerning the programme. The major findings regarding potential development actions are the following:

- **Learning assessment:** It is a challenge to assess CDIO skills in the evaluation. This is a challenge for all programmes at DTU and probably all CDIO programmes by and large. Ways of improving assessment of CDIO skills will be considered in the future.
- **Validation of learning outcomes by stakeholders (in particular, students and industry):** This kind of validation is done only to a certain extent at the moment. Ways of improving this in the future will be considered, ie. with more systematic discussions with the advisory boards and using scheduled graduand surveys.
- **Alignment of learning objectives at course level and competence profile for the programme:** The programme has been developed according to the goals set by the CDIO standards for some years already. However, the competence profile must be more properly aligned with the learning objectives at the course level. There are a few of the qualifications in CDIO syllabus category 4 that are not yet addressed properly in the study programme (in particular, 4.3, 4.6 and 4.7). The possibilities for incorporating these qualifications in the study programme in the future should be discussed.
- **CDIO awareness:** A “helicopter document” that shows the ideas behind the study programme and describes the structure and progression of the programme should be produced. The content of this document must be well known by all teachers in the study programme and should be revised every year in order to be constantly updated. There still is a high degree of privacy about teaching and evaluation methods. It seems that there is a great potential for improvement of the communication among teachers. More systematic meetings in teacher teams are a possibility. In the BEng programme in Chemical and Biochemical Engineering at DTU the students work in the phases C-D-I. The only possible contact with the O-phase is in the engineering training in the industry. It is difficult to work with the “Operate”-phase in chemistry. How this phase can be treated should be taken in examination.

Case Metropolia

At Helsinki Metropolia University of Applied Sciences, the implementation of strategy, the operations and achieving the objectives are evaluated systematically. The operations are enhanced and improved based on the results from the evaluation and feedback systems so that Metropolia provides services to meet the needs of our customers, i.e. students and other stakeholder like industry, organisations and society.

The operations of the institution are developed in a co-operative way together with staff, students and stakeholders. The implementation of the major objectives of Metropolia, and developing its operations, quality and competitiveness are based on continuous improvements according to principles of PDCA (Plan – Do - Check - Act).

The Quality Assurance system is based on strategic leadership and management, supportive core processes, information and feedback systems, described processes and their guidelines and organization and responsibilities.

The implementation level of CDIO approach has been carried out in 2009, just one year after Metropolia became a collaborator in CDIO. The results were not so reliable due to the diverse viewpoints towards CDIO, but the evaluation was a good start-up to increase the awareness of CDIO as a concept.

In 2010, a self-evaluation process was carried out and it was based on the new strategic objectives which were set for the entire Metropolia:

1. Highest throughput in Finland
2. Customized and efficient processes
3. Best teaching in Finland according to the feedback of students
4. Best working place in Finland based on the great work places contest
5. Eligible strategic partner (in partnerships and in international networks)
6. Expertize and qualified employees to the region
7. Economic freedom to maintain the HEI autonomy

Key findings of the self-evaluation in SWOT-format are shown in the figure below.



Figure 1. SWOT of Metropolia.

We identified the development areas and we are facing four major challenges:

1. How to supervise and manage a great number of innovation projects running simultaneously
2. How to increase the knowledge of students of developing an international career in engineering. Some actions have been taken, including the following: International ICT week for international and domestic students
3. To manage better the work placement arrangements - improve the connection between industry and Metropolia
4. Integrating teaching activities, increasing CDIO awareness and carrying out the implementation

DISCUSSION

The project met well all the planned objectives:

- 1) Guidelines and evaluation criteria for self-evaluation process have been created.
- 2) Each HEI has documented their participating degree programme in detail.
- 3) Each participating programme has done the self-evaluation.
- 4) Each programme has identified the main development actions based on the self-evaluation.
- 5) Understanding of other partners and their challenges has increased.
- 6) The quality assurance has been developed in each participating programme.

The guidelines and evaluation criteria for self-evaluation process were successfully used. The developed self-evaluation model functioned, but at the same time it was a very time consuming process. However, the process was also rewarding in the sense that those who have been working with the report have gained a very good overview of the programme. Furthermore it is valuable to be “forced” to look closer at one’s own programme.

The self-evaluation documentations were very thorough and they described the programmes well. In this sense, it seems that the guidelines and criteria provide useful help for the self-evaluation. Finally, the self-evaluation helped the programmes to identify possible development areas. Now the programmes have material and evidence for programme development. Interestingly, the development areas were partly overlapping and showed common needs for development, which could promote future co-operation.

The self-evaluation contained rating the performance with the CDIO standards. In this project we still used the older set of standards where there were no individual rubrics for each standard. This scoring is a rewarding and easy way to show progress in development, but it does not guarantee comparability with other programmes. The scoring is still a very subjective process. Therefore it is important that reasonable rationales for the scores are attached, because otherwise it is difficult to show and analyze the progress. The new CDIO standard version with the rubrics is a step forward.

The co-operation between project partners has been successful and deepened since the beginning of the project. Every partner HEI has been committed to the project objectives and timetable. Regular meetings between project partners have been very fruitful and given plenty of new development ideas. The project has started a close cooperation between the Nordic partners and we intend to continue working together in the area of quality assurance in education in the future. All experience gained from self-evaluation work will be utilized also in the future while evaluating degree programmes in individual HEIs.

CONCLUSIONS

The self-evaluation model created in this project is a good tool for improving quality assurance in higher education. The model provides easy-to-follow guidelines and criteria for self-evaluation. However, the model also needs some modifications, such as the exact content of the self-evaluation report, that are going to be discussed at the end of the whole project.

The project focused on engineering education, and thus the participating HEIs and degree programmes represented the engineering field. Although the educational challenges nowadays concern higher education in a general level, especially engineering education is challenged to develop new methods of quality assurance work in order to produce experts that meet the growing demands of working life. However, the project results can be further developed and adapted also to other educational fields by refining the methods and tools produced during this project.

The project encouraged the programmes to do self-evaluation and to define the development areas. Hopefully the project also created a quality assurance spirit into the programmes and self-evaluation will become a regular method in quality assurance of the programmes.

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CDIO AND RESOURCES - CAN WE DO IT ON THE CHEAP ?

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ABSTRACT

Universities are continually under pressure to do more in terms of delivery, for less in terms of resources. For engineering and design courses, particularly those where a high level of practical project work is expected, this can be a particular challenge. Restriction of resources can be manifested in many ways, including limits on staffing, modest equipment availability, and constrained consumable budgets. Sometimes this may be a temporary situation, such as when infrastructure lags new project based teaching initiatives but can equally be an ongoing pressure as budgets are squeezed. This paper looks at some of the pressures associated with running practical based teaching programmes and explores some ways in which some measures of mitigation can be put in place.

KEYWORDS

Project-based learning, Resource management, Cost-effectiveness

INTRODUCTION

Universities are continually under pressure to produce increasingly high qualities and volumes of teaching and research for given levels of resource. For arts, business and social science subject areas, taught largely through lectures, this is generally achieved by increasing class sizes. For science and technology based courses there is often pressure to use similar methods to ensure cost effective courses are delivered. This is most often embodied by common first year classes within Engineering faculties. This limits the amount of practical teaching, the level of two-way interaction between staff and students and can produce bland programmes designed to fit a range of disciplines. The reduction in practical classes also makes way for the rationalisation of specialist teaching space and technical support.

UK Context

In England funding for teaching of domestic University students comes from the Higher Education Funding Council for England (HEFCE). This allocates block grants to University based on a complex formula but is significantly driven by the numbers of students and the degree subjects they are undertaking. The funding regime can be seen in table 1.

Table 1
HEFCE Undergraduate Funding Regime 2010-11 [1]

Type	Description	Multiplier	Resource (£)
A	Clinical medicine, dentistry etc.	4	15804
B	Lab based science and engineering	1.7	6717
C	Courses with field or studio element	1.3	5136
D	Other courses	1	3951

These figures are typically supplemented by fees of around £3375 which are chargeable to students. Once these are factored in, the ratio of funds per student between engineering (Type B) and say business courses (Type D) will drop from 1.7 to around 1.4. It is this more modest differential which engineering programmes within the UK must use to cover the smaller class sizes, need for specialised workshops, laboratories and equipment, specialist support staff and increased consumables. It should be stated at this stage that following the Browne report into the funding of Higher Education funding fee levels are likely to increase dramatically from 2012 to around £9000, with government funding only existing to support the differential to the strategically important A and B type programmes [2]. The implications of this change are still unclear and discussion of this is beyond the scope of this work.

CDIO Context

CDIO is very much focussed on providing a student centred learning experience based on learning by doing. As such it features within its standards, a requirement for among other things, design build experiences (standard 5) and CDIO workspaces (standard 6) [3].

To achieve these, institutions must balance the demands associated with delivering high quality CDIO learning with possibly constrained budgets and resources. Can we do CDIO on the cheap ?

INTRODUCING CDIO ACTIVITIES

Our own experiences relate to introducing CDIO as part of a family of Mechanical Engineering and Product Design programmes. These typically have an intake of around 60 and 40 students respectively and prior to CDIO were largely taught separately. Both degrees normally last three years, with an optional industrial placement year between years two and three.

CDIO is currently rolling out from year 1 and as a major new initiative some limited funding was secured. This provided for basic redecoration of a workshop space and sets of hand tools for groups of students. Our operating budget for consumables and our technical and academic staffing was much as in the previous lecture based programmes.

Our situation was therefore constrained and this was further hampered by the improvements to the workshop being delayed, preventing access to this space by the students for much of the first semester. CDIO activity was therefore forced to operate from pooled general classrooms. This limited the activity possible and also prevented students returning between timetabled sessions to further develop their project work.

The aim of the first semester module was to introduce students to CDIO and let them experience a number of engineering and project management concepts. This was to be achieved through a variety of one to three week mini-projects.

The second semester module had a theme of sustainability and was primarily based around a windbelt – a novel form of wind turbine. This featured a mix of short, tightly controlled mini-exercises capped with a four week main project.

A variety of images from the projects can be seen in figures 1-3. Figure 1 shows the Rube Goldberg week 1 exercise in which students, having been newly set into teams constructed chain reaction type systems from scrap material.



Figure 1 : Rube Goldberg Exercise



Figure 2 : Bridge Project

Figure 2 shows an example of the first semester bridge project. In this case wooden pallets were provided to each group to build a small bridge to span a 2m gap. Fixings in this case were restricted to string to encourage careful thought in the build and design of the bridges.

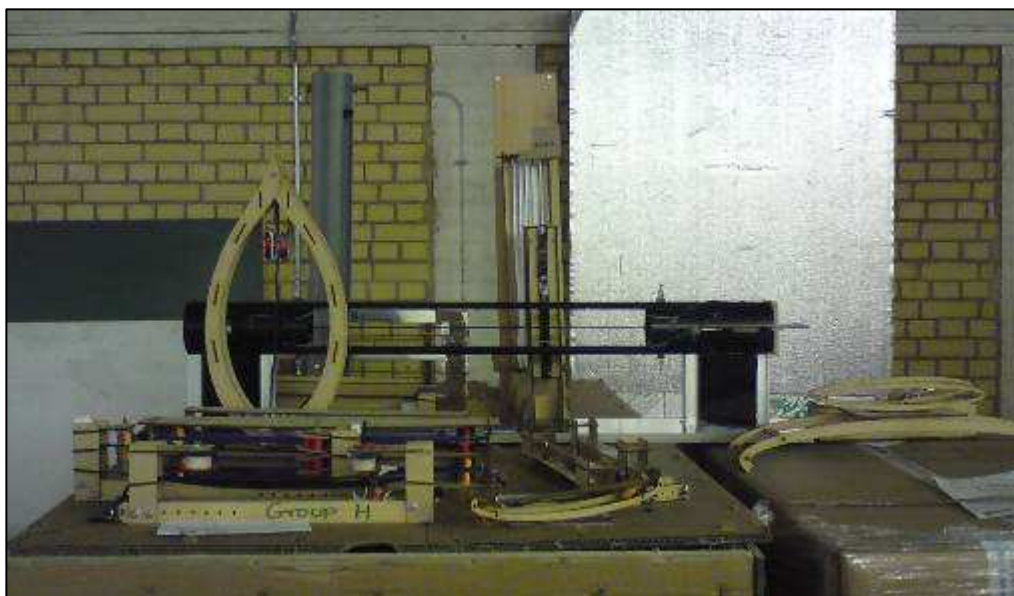


Figure 3 : Windbelt projects

Figure 3 shows a variety of windbelts produced as part of the second semester capping exercise. In most cases a mix of university (copper coils, MDF, magnets etc.) and student sourced materials were used.

The aim of these exercises was to help students develop an enthusiasm for engineering and design. Setting open ended projects with no predetermined outcome allowed students to consider a risky, innovative and fun approach to their work.

COST ANALYSIS OF PROJECTS

While it can be difficult to give an exact cost per student per module we have attempted to evaluate this to help in allaying fears that practical modules are often massively costly. Where possible low cost materials were utilised, with extensive use being made of redeployed packaging card and pallets.

Tables 2 and 3 outline the activities carried out in the 1st and 2nd semester year 1 modules. These include contact time for academic and technical staff but not the additional hours associated with class set up or marking. While these were not insignificant it was felt that once the programme was rolled out these would be in proportion to the taught hours.

From a staffing resource issue it is generally the total staff man hours associated with delivering a course which are of concern, whereas for materials, the cost per student are the more common pressure.

Table 2
CDIO 1.1 Design & Exploration

Activity	Concepts	Material Cost (£)	Academic Time (man hours)	Technician Time (man hours)
Rube Goldberg (1 week)	Ice breaker, What is CDIO ?	20	14	12
Golf Ball Packaging (2 wk)	Estimation, Design Communication	30	14	6
Visual Communication	Technical Drawing & Sketching	10	7	0
Bridge Building (2 week)	Prototyping & analysis in build	200	14	6
Pump Stripdown (2 week)	Intro to materials & manufacture	200	14	14
Capping CDIO (3 week)	Reinforcement of lessons	50	21	14
	Total	510	84	52
	Total / student	5.10	0.84	0.52

Table 3
CDIO 1.2 Prototyping & Development

Activity	Concepts	Material Cost (£)	Academic Time (man hours)	Technician Time (man hours)
Product stripdown (1 wk)	Material use and reuse, Design for Sustainability	100	14	0
CDIO Academy Ideas Generation (1 wk)	Ideas Generation – Conceive	10	7	0
Wind Turbines (2 wk)	Energy conversion, efficiency in systems	200	21	3
Wind Belt Investigation (3 weeks)	Experimental investigation, product improvement, Idea evolution. CAD	200	21	6
Capping CDIO (4 weeks)	Reinforcement of lessons Business considerations	200	28	14
	Total	710	91	23
	Total / student	7.10	0.91	0.08

DISCUSSION

The material costs per student for running the two CDIO modules was around £12.50. These modules account for half of the total student experience in their first year but in relation to the income (Table 1) these costs are insignificant.

The staff hours for CDIO can appear relatively high. Several sessions were double staffed with academics however this became much less the case as the programme evolved. Nonetheless had these programmes been taught entirely through lectures the contact hours would have been near identical. Under our previous programme the six modules replaced by CDIO would each have featured around 30 contact hours – 180 hours for the year as against around 175 through CDIO.

CDIO has also replaced many traditional lab courses where students were rotated around labs in small groups under the supervision of technicians. Typically a single lab exercise could take between 30 and 50 hours of technician support time but whole class CDIO teaching has significantly improved matters.

CONCLUSION

This exercise has shown that CDIO with its high level of practical and project work need not be a significantly expensive exercise in comparison to more traditional methods. It is naturally the belief of the CDIO community that improved retention and quality of graduates are a key measure of the cost-effectiveness of a programme. These do however tend to be longer term aspirations which can be difficult to quantify when faced with pressure as finance, staff and space requirements are tightened on an annual basis. It will be a major challenge to the CDIO community to share positive ideas and experience to ensure CDIO can be seen as a cost effective activity.

WORKSHOP

As part of the 2011 CDIO Conference a workshop will be held to pilot a new low cost CDIO learning activity. We seek interested parties to join us in refining this and sharing ideas for economic CDIO based activities.

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ABSTRACT

Seeking to connect the cognitive sciences and teaching faculty, Susan Ambrose and her co-authors recently published, *How Learning Works: 7 Research Based Principles for Smart Teaching*.^[1] Ambrose and her co-authors observed that cognitive and educational psychology was making great strides advancing the science of learning, but little of this science was impacting college classrooms. Ambrose *et al.* sought to connect effective teaching practices and cognitive psychology's advances in our understanding of learning and bring that science of learning into others' classrooms. Their book distills seven principles from the learning sciences, and then instantiates those principles with concrete teaching practices.

We find in Ambrose's work a substantiation of project-based learning in engineering, providing a foundation for understanding why this pedagogy works. Specifically, problem-based learning works because it naturally embodies all seven research-based principles of effective teaching and learning outlined by Ambrose and her co-authors. Appropriately executed, project-based learning implicitly complies with our students' ability to learn. We elaborate on four of Ambrose's seven findings and describe how the documented practices of emerging from the CDIO initiative instantiate those principles. Furthermore, Ambrose's principles suggest criteria by which we might justifiably identify *best practices* in project-based learning. This assessment may help promote and facilitate adoption of fine-tuned educational strategies within the CDIO framework. Furthermore, this will shift the arguments for project-based learning from appeals to intuition and trial-and-error to a more rigorous foundation built from the teaching and learning sciences.

KEYWORDS

Learning science, project-based learning, CDIO, cognitive psychology.

INTRODUCTION

Proponents of CDIO and project-based learning commonly hear the question, "What evidence do you have that it works?" In other words, photos of smiling student teams make nice presentations, but are these students really better engineers as a consequence? Formally, what body of research indicates that project-based learning represents a more effective pedagogy? Admittedly, while our disciplinary scholarship is data-driven, our pedagogy has depended largely on intuition and trial-and-error approaches based on what has (and has not) worked well in the classroom.

Seeking to connect the cognitive sciences and teaching faculty, Susan Ambrose and her co-authors recently published, *How Learning Works: 7 Research Based Principles for Smart Teaching*.^[1] Ambrose and her co-authors observed that cognitive and educational psychology was making great strides advancing the science of learning, but little of this science was impacting college classrooms. College professors in other fields are unlikely to read cognitive psychology journals, or attend educational psychology conferences. Hence, this flourishing science of learning has been cloistered in an ivory tower on the other side of campus. Ambrose *et al.* sought to connect effective teaching practices and cognitive psychology's advances in our understanding of learning and bring that science of learning into others' classrooms.

We find in Ambrose's work a substantiation of project-based learning in engineering, providing a foundation for understanding why this pedagogy works. Specifically, project-based learning naturally embodies all seven research-based principles of effective teaching and learning outlined by Ambrose and her co-authors. Appropriately executed, it implicitly complies with our students' ability to learn. Our paper elaborates on four of Ambrose's seven findings and describes how the documented practices of project-based learning in engineering instantiate those principles. Furthermore, Ambrose's principles suggest criteria by which we might justifiably identify *best practices* in and project-based learning. This assessment may help promote and facilitate adoption of fine-tuned educational strategies within the CDIO framework. Furthermore, this will shift the arguments for project-based learning from appeals to intuition and trial-and-error to a more rigorous foundation built from the teaching and learning sciences.

Ambrose *et al* distill seven principles from the burgeoning scholarship of learning, which they pose as foundational insights for teachers/professors seeking to improve their students' learning. Their presumed audience is undergraduate faculty, as evidenced by their selected examples, but the principles are no less applicable to other learning contexts. These principles are:

1. Prior Knowledge: Students prior knowledge can help or hinder learning.
2. Knowledge Organization: How students organize knowledge affects how they learn and apply what they know.
3. Motivation: Students' motivation generates, directs, and sustains what they do to learn.
4. Mastery: To develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they've learned.
5. Practice: Goal directed practice, coupled with targeted feedback, are critical to learning.
6. Student Development: Students' current level of development interacts with the social, emotional and intellectual climate of the course to impact learning.
7. Metacognition: To become self-directed learners, students' must learn to assess the demands of the task, evaluate their own knowledge and skills, plan their approach, monitor their progress, and adjust their strategies as needed.

A chapter of Ambrose's book is devoted to each of these principles, following a common structure. That structure flows from stories illustrating each principle, a diagnosis of the

stories, a summary recounting of the research findings, and then research-informed suggestions for improving student learning.

While we believe that all seven of Ambrose's principles pertain to project-based learning, our paper will concentrate on four. In each case, we'll elaborate shortly on the principle, discuss how project-based learning complies, and finally how thoughtful application of the principle might improve those practices.

The CDIO construct is developed more fully in other sources [2]. We'd like to briefly clarify several important terms, where questions frequently arise. While project-based learning is an important element of the CDIO construct, appearing explicitly as CDIO Standards 5 & 6, it is but an element. (See reference [3] for the general goals and strategies of project based learning.) CDIO program standard #1 speaks of embracing engineering product development as the *context* for engineering education. *Contextual learning* we distinguish from project-based learning to emphasize that projects are designed not only with the goal of developing particular disciplinary knowledge but also the professional skills of engineers, such as writing, speaking, ethics, systems thinking. Where used, projects are set in a context which replicates the activities of an engineering enterprise doing the work of conceiving, designing, implementing, and operating engineering systems. Contextual learning is frequently embodied in hands-on, design-implement projects (project-based learning), but may also be found in learning activities that replicate business activities that do not require fabrication or fit the mold of "projects". Therefore contextual learning and project-based learning commonly overlap or coincide in CDIO programs, but project-based learning need not be contextual, nor contextual learning necessarily project-based.

Figure 1 depicts the foundational goal of CDIO, drawn from [2]. Specifically, we do not simply seek to move to the right in merely improving our students' learning of our disciplinary content. Our ambition is to move our programs up and right, simultaneously targeting deep learning of our disciplinary content *while* growing in the professional skills of engineers. This is how we believe problem-based learning varies in substance with a more narrow understanding of project-based, or project-centered learning, which may or may not target both disciplinary and professional development.

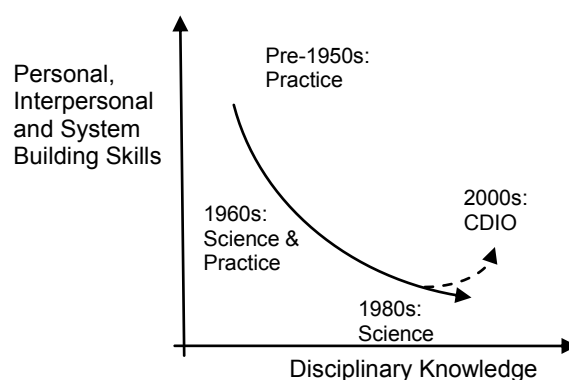


Figure 1. The Trajectory of CDIO's Desired Engineering Education Reform

In the sections that follow, we've picked four of Ambrose's seven principles to elaborate, exemplify, and then draw suggestions for excellent research-based practices in project-based learning, though many of our observations will also apply to contextual learning. We'll briefly address the three remaining principles at the conclusion.

OUR OBSERVATIONS

Principle 1- Prior Knowledge: Students prior knowledge can help or hinder learning.

Professors commonly assume that students have learned and retained basic skills from prerequisite courses, an assumption that may be further strengthened by the student's self-report. The issue is whether the Professor and the students have the same references; there may be a mismatch between knowledge that the students have or believe they have, and the knowledge the instructor expects for their course. Hence Ambrose's first principle:

Students prior knowledge can help or hinder learning

Activate prior knowledge

In order that their prior learning help in the new context, the professor must connect new content to prior knowledge and experiences. However, that prior knowledge must be appropriate to fit with new knowledge. Misconceptions and inaccuracies in prior knowledge may interfere with the learning of new material. Not all prior knowledge provides a solid foundation for new knowledge. Nevertheless students interpret new information based on their prior knowledge, whether accurate or false.

Students may not make connections to relevant prior knowledge, which makes new learning difficult and when prior knowledge is inaccurate or inappropriate, it will distort new learning. Students must connect new knowledge to previous one in order to learn [4] Students commonly lack training in activating prior knowledge. Often minor prompts can activate relevant prior knowledge. This can often be done if the problem is stated in the context of applications or a design problem. Team-working with discussion sessions in capstone design play an important function in activating prior knowledge as students will often ask the question, "why?" Researchers call this process *elaborative interrogation*. Project based learning, especially in small teams, provide a fruitful environment where students can readily connect what they are learning to what they already know. Cross-department teams, where a team includes majors from more than one program, are advantaged here. A mechanical engineer might have studied electrical motors in his required EE courses, but carried misconceptions into her design team's work. A EE student with more depth in the subject might quickly recognize their teammate's confusion and correct it, providing insight which even a faculty member from another discipline might not appreciate. Mazur comments on the effective proximity of students to their peers' misconceptions [5].

Accurate but Insufficient Knowledge

In the case where the prior knowledge is insufficient but accurate, the new learning may become challenging. Students may have simply forgotten the details from prerequisite courses because the context of why the material is taught was not clear to the student. Engineers develop primarily declarative knowledge, or knowledge of facts and concepts that can be stated or declared.

A second knowledge is the procedural knowledge where knowledge is about when to apply a certain procedure, method or theory. With this knowledge students develop the skills when and how to apply their declarative knowledge.[6] In the self-directed learning environment of the design courses, students learn to recognize insufficient knowledge and can mitigate the deficiency. Further, the knowledge activation environment of a team can activate declarative knowledge in one team member and procedural knowledge in another student. A synergy of knowledge development is activated in project passed team learning. In a traditional lecture class it will remain a challenge to the teacher to mitigate insufficient knowledge negative reinforcement which is perceived punishment with bad grades [1].

Inappropriate Knowledge

Students may draw upon superficial information from other experiences and include a bias in their interpretation of a new knowledge. They may have been used to applying analogies for understanding a concept. Analogies have limits and it is essential to recognize these limits. Such a task requires careful analysis and students may not yet be at an intellectual point where they have clear references for such a comparison.

Knowledge is also related to group cultures or discipline cultures. Engineering students commonly learn English writing principally from English Departments that cherish particular writing styles. That writing style constitutes inappropriate knowledge for many aspects of engineering reports, particularly since argumentation is commonly deductively organized. In this case it is necessary to teach students the concise, precise and clear language requirements that engineers interpret in the desired context, and the inductive flow of technical reasoning. A good technique for testing engineering clarity of a text is to give team members and non-team members the draft to read and check whether they understood fully after first reading. Such an environment is provided by the design team organization in project-based learning.

Inaccurate Knowledge

Inaccurate knowledge is often disseminated through web based media and bragging rights of individual citizens. Such knowledge is not solid and the owners may change opinions on the fly. In the declarative knowledge of engineering inaccurate knowledge can often be corrected. Scientific claims in some domains, however may remain contentious. Such opinions may be misconceptions and are difficult to refute for many reasons. Reasons may be within limited scientific evidence or coming from groups with a specific agenda for their own benefit. In traditional engineering lectures the teacher may not provide sufficient proof that some concept residing in the students head is inaccurate or wrong.

In contrast, in engineering design the work focuses around technologies that are already proven to a set technical readiness level. Components that are designed to provide a defined function provide it or do not provide it. Students must verify properties and functioning, and validate the outcome. The student might have had a different understanding of how a system functions, but the results of her work will instill the correct knowledge in the student. This process is also often referred to as “experience”. It is common to see students presenting a technical design to an experienced machinist who tells the student at first sight “that does not work!” The next time the student returns, her system will probably “work”. Project-based learning is an excellent method to correct inaccurate prior knowledge.

Strategies to Activate Prior Knowledge

Project-based learning puts the learning requirements in the context of engineering technology. If the project is related to the specific field of engineering studies, the students with a pre conceived preference for that topic will be highly motivated to learn. The team projects courses offer an excellent environment to develop new knowledge with activated good use of prior knowledge. In the teams, students benchmark their knowledge on a continuous basis, which synergistically activates prior knowledge in all team members. It does normally not need to have a diagnostic assessment of prior knowledge. As teams are to some degree self-directed, individual students tend to correct any knowledge deficiencies on their own. During the design team students have to develop requirements for the project, evaluate design architectures and find a system that they will manufacture and test. This effort requires a significant amount of brainstorming, which reveals prior knowledge in each student. The concepts they develop for the chosen architecture will include subsystems that

are interfaced with energy or data flow, they may include mechanical, software and electronics components.

In an early phase students predict the performance of their project gadget based on select assumptions and perhaps back-of-the-envelope calculations. A test plan needs to be developed to verify the predictions. Teams have to justify why their design will work and how it will work. Errors and mistakes often happen at interfaces between subsystems. In the team discussions prior knowledge that has developed in the design process again will be activated in all team members with a good chance that most errors can be corrected. If not in the design phase errors will show up during implementation and operation phase of the project.

Project-based learning provide excellent vehicles to activate prior learning. Team working triggers prior knowledge in all team members. Projects are seen in the context of engineering applications which increases motivation and helps activate prior learning and increases the efficacy of the student. Incorrect prior knowledge will be corrected after personal initiative of the individual student, or at the initiative of classmates in team projects, thus relieving the teacher from having to carefully assess the prior knowledge of each individual student.

Principle 2: Knowledge Organization

University students tend to be presented with and learn largely disassociated “elements” of knowledge – facts, concepts and methods. Yet knowledge is not simply a set of disconnected facts, it is a *system* with facts, concepts and methods, as well as a network of connections among these elements, a noetic structure. In the language of engineering systems – knowledge is a *system*, with both entities (facts, etc.) and relationships (connections). The emergent property of this system is the ability of the thinker to solve problems and apply the knowledge in new ways.

To quote Ambrose: “As experts in our fields, we create and maintain, often unconsciously, a complex network that connects the important facts, concepts and procedures, and other elements of knowledge within our domain. Moreover, we organize our domain knowledge around meaningful features and abstract principles. In contrast, most of our students have not yet developed such connected or meaningful ways of organizing the information they encounter in our courses. Yet how they organize their knowledge has profound implications for their learning.”

This line of reasoning leads to Ambrose’s second principle:

How students organize knowledge influences how they learn and apply what they know.

Embracing this observation, we as experts can start to appreciate the subtlety of the organization of knowledge we possess. For example, an expert on solid mechanics would certainly hold a structure among the principles and methods to solve a mechanics problem – equilibrium, compatibility, and constitutive relations, for example. But the organization of knowledge even in our own minds is not unique – the same solid mechanic would have a structure around how equilibrium is used in a number of fields, and another on how certain tensor relationships interrelate.

We must then realize the lengthy development of this organization, and how much better we might perform as instructors if we explicitly help students develop the organization. As a simple example, we remember how confused we were by the relationships among force, work, energy and power. It was well into our university studies before this structure became intuitive, despite the fact we had been confronting it for almost four years. To take a more complex example in engineering, almost all struggle with the relationships between the

second law of thermodynamics and other knowledge. It was only after Claude Shannon made the connection between work/heat and signal/noise that he was able to articulate the famous information theorem that now bears his name.

Ambrose cites a number of methods that instructors can use to make students more aware of the organization of knowledge, including having both the instructor and students draw concept maps, making explicit the organization of the course, and making connections between concepts explicit. These approaches are primarily focused on classroom instruction.

Alternatively, we can use projects as a learning medium for conveying structure. The execution of a design-implement project by a student allows them to understand the authentic organization of knowledge for synthesis. If executed early in the education, it can provide a foreshadowing of the details of the knowledge that will be learned, and give a roadmap for its organization. Projects can bring out deep organization of knowledge as a highly interconnected body, in contrast with courses that normally present a serial view of facts and methods. This is particularly true over the semesters of an engineering degree, where projects can scaffold skills progressively (we'll return to scaffolding later).

Consider an example of learning knowledge organization using the Lighter-Than-Air design-implement project for first year students developed at MIT. Students in teams of about six design a remotely piloted buoyant airship, driven by a electric motor driving a propeller [7]. They then build the airship, using balloons full of helium, lightweight structural materials (soda straws and tape), and a RC controlled servo controlling either a rudder or propeller. Inside a gymnasium, a competition takes place in which the students fly their airship around a set of pylons for minimum time.

This project is deliberately designed to be rich with knowledge relationships, and to be an authentic experience in aerospace design in which first year students can be successful. Among the many organizations of knowledge, ones the students encounter are:

- The relationships among stiffness, strength, weight, and structural density of lightweight structures
- How vehicle configuration, power, drag and maximum velocity are connected
- The equilibrium relationship among configuration volume, mass and lift
- The relationship between available electric power, thrust, delivered thrust power and propeller design
- How turn rate is interconnected with body shape, forward velocity, side force and control authority

Another process related organization of knowledge that the design build experience illustrate are the sequential (but often iterative) steps of requirement analysis, design, build and testing. This is a great example of an activity leveraging project-based and contextual learning.

The student will obviously not leave the first year course deeply understanding all of these individual topics (configuration, vehicle dynamics, propeller design, customer requirements, etc.) but they will develop a sense of the relationships among the topics. Contrast this resulting structure of knowledge that the student would develop with the traditional scenario in which a student learns structures in one track, fluid mechanics and applied aerodynamics in another track, propulsion in a third, and vehicle flight dynamics in a fourth, perhaps later integrated in a capstone design or design-build class.

In a corroborating exhortation, Harvard's David Perkins notes that effective teaching will seek to introduce the student to "play the whole game." [8] By this he means that learning goal's is the ability to DO something. The student sees the value of component knowledge in the context of their ability to perform some larger task. The challenge for teachers is the design of student work that's a whole activity, setting the context. One of the failures of reductionist engineering science is the descent into detail, remote from context, and the consequent

disconnect from application, the student's perception that they're now enabled to do something with their knowledge.

Perkins observes, "We can ask ourselves when we begin to learn anything, do we engage some accessible version of the whole game both early and often? When we do, we get what we might call a 'threshold experience', a learning experience that gets us past our initial disorientation and into the game." In engineering education, that means getting students into the "whole game" of conceiving-designing-implementing-operating an engineering system in a mission or enterprise context. Furthermore, Perkins insists such experiences be done not simply as a capstone, but "early and often."

The use of project-based learning as a way to develop structure is further supported by the Ambrose's research summaries. The first of these points is that "no organizational structure is necessarily better or more 'correct' than another." She goes on to point out that knowledge organizations are most effective when they are well matched to the way that knowledge will be accessed or used. From this we can see that the desirable organizational structure for students who will go on to engineer – that is design and build new systems – is in fact the structure that would evolve by practicing designing and building in projects while students. This is in contrast, perhaps, with the organization that is understood by a faculty member who is a researcher in the field. So project-based learning with authentic engineering activities will develop the organization that will support successful engineering development.

When students are exposed to an organization of knowledge before being exposed to the details, they are actually better able to learn. Ambrose states "student show greater learning gains when they are given an *advanced organizer*, that is, a set of principles or propositions that provide a cognitive structure to guide in the incorporation of new information." This is exactly one of the roles of an early design-implement project– to build the cognitive framework for the future learning of technical fundamentals. When faculty who teach theory question the value of "wasting time" on early projects, this is the most effective argument – that the projects will help the students learn the abstractions that follow. Early exposure "whole game" provides context for the necessary disciplinary detail to follow.

A third point that emerges from the research is that novices tend to develop more simplistic or superficial organizations of knowledge than do experts. Experts recognize meaningful patterns. Engineering students may, for example, classify equations as linear, quadratic, or differential, while a more expert observer may classify them by the phenomena the equations represent. Ambrose concludes that "we need to provide students with the appropriate organizing schemes or teach them how to abstract the relevant principles from what they are learning." One way to teach deeper organizing schemes is to use project, and particularly advanced design-build projects in the later years of education.

In summary, design-implement projects are an excellent way to apply the principle of knowledge organization. Projects build an authentic organization that will be useful for students' future, in the earlier years of education, they can be used for advanced organizers, and in the later years they serve to teach deep, and not superficial, organization.

Principle 5: Practice

Project-based learning should positively implement Ambrose's fifth principle:

goal-directed practice coupled with targeted feedback are critical to learning.

In order to be successful, conceive-design-implement projects must have clearly defined goals for the students to achieve, and students should have multiple opportunities to practice such projects within their undergraduate curriculum (e.g., "cornerstone" and "capstone")

design projects). Conceive-design-implement projects inherently have multiple opportunities for targeted feedback on the project itself, as many projects are managed using a stage-gate or phased approach to ensure timely completion. Such project can also be paired with writing-intensive course requirements to provide additional opportunities for feedback—and practice—beyond the project itself.

We'll use Penn State's Learning Factory as an illustration of the application of this methodology. At Penn State, Ambrose's fifth principle is best embodied within the capstone design projects undertaken by senior engineering students. Like many universities, these capstone design projects are performed collaboratively with industry, allowing for multiple levels of feedback. When submitting their project descriptions, companies are explicitly asked to clearly define the goals and deliverables for their project, which each instructor reviews prior to the start of the semester and then with the students when classes start. This ensures that not only are the students and faculty on the same page, but both parties are on the same page with the company sponsor as well. Ambrose warns that "Instructors often think they are conveying specific goals to students when, in fact, they are not", and this goal setting practice occurs on multiple levels to ensure a successful capstone experience. For instance, students and sponsors are encouraged to sign off on a Deliverables Agreement during their initial site visit to the company after they have carefully reviewed the project with the sponsor. This helps ensure that "goals are stated in such a way that students' performance can be monitored and measured", while ensuring student "buy-in" with the project. Finally, given the breadth of ABET criteria that the capstone course satisfies in most departments, course syllabi in capstone design courses across the College of Engineering at Penn State are carefully reviewed each year and agreed upon by faculty in other departments to allow students to move seamlessly between sections. This allows single and multi-disciplinary design project teams to be easily formed based on the needs of the projects as each department has already agreed upon what it "really wants students to learn" through this syllabus review process. As the capstone design projects are executed, they naturally satisfy the dual goals of the sponsoring companies and the faculty.

Ambrose cautions that "practice [students] do should be at an appropriate level of challenge and, as necessary, accompanied by appropriate amount and type of support". While some faculty utilize some form of knowledge and skill assessment at the start of their capstone design course as Ambrose suggests, students at many institutions self-select projects on which they would like to work for the semester or year. In particular, capstone design project descriptions across the participating departments are compiled into a single list, which is distributed to all faculty and students (each Fall semester, 8 engineering departments participate in the capstone design program coordinated by Penn State's Learning Factory; in Spring, this number jumps to 11). Students are allowed to work on any project that needs their disciplinary expertise (e.g., an industrial engineering student can work on any project that needs an industrial engineer but not a project that needs, for example, only electrical engineers). During the first week of the semester, all of the company sponsors participate in a Project Kickoff even wherein they field questions from students that further inform their project preferences. A student typically comes to the Project Kickoff with 6-10 projects in mind and then uses the Kickoff to identify which projects are of most interest and at the right level (e.g., scale and scope) to challenge them. At the end of the Kickoff, students rank order their top five project preferences, and this information is then used to assign students to teams (3-5 students per team), balancing course and project needs with student interests and skills as best as possible. This process allows students to match their skills and interest to an appropriate level of challenge, helping to avoid the pitfall that Ambrose notes when there is a mismatch: "If a challenge is too great, learners may have a negative expectation for success and hence become disengaged and apathetic. In contrast, if students feel that the challenge is reasonable, they will likely hold a positive expectation for success that will increase their tendency to persevere and work hard for the goal."

Support for each project then occurs on two levels. First, faculty meet regularly with each team to review their progress. Each team is required to prepare a weekly memo indicating what they have accomplished in the previous work, what they are working on during the current week, and what they plan to work on in the coming weeks. This weekly memo is also sent to the company sponsor, who provides technical support for the project. This weekly interaction with industry is what makes the capstone design projects so successful—without this “real world” element and the interactions with subject matter experts from industry, these projects would be no different than any other class project. Mid-semester and end-of-semester evaluations from the sponsors are also used to provide guidance to the teams, and most faculty include these evaluations as a portion of each team’s grade (e.g., 5%-10%). Finally, teams are also encouraged to seek additional faculty or staff support as needed for a project to reinforce the importance of self-directed learning in the course.

These weekly meetings help ensure that “Goal-directed practice [is] coordinated with targeted feedback in order to promote the greatest learning gains.” Faculty also meet with all of their teams as a class once a week to provide feedback at the group level, e.g., project reporting requirements, expectations for presentations, etc. Project reports are tied closely to the stages of the project (e.g., concept development, preliminary design, detailed design, final design), and a report template and example reports are provided to the students to “show students examples of what the target performance looks like”. Coupling feedback with practice, faculty also require draft versions of team reports 2-3 times during the semester. This allows team-level feedback and the opportunity to revise the report (usually within a week’s timeframe) and improve their technical writing skills through repeated practice. Students are also encouraged to review past project posters (on display throughout the hallways in participating departments) and project summaries (available online through the Learning Factory’s website) and prepare drafts for faculty to review prior to the end of the semester when they are due. To facilitate this process, most faculty provide students with a copy of the grading rubric used for each report. As Ambrose points out, “This [helps] students become better at identifying the qualities of good work and diagnosing their own problems.” Likewise, the judging criteria that are used by industry judges to identify the Best Projects and Best Posters at the Design Showcase are shared with students early in the process to reinforce the course goals and sponsor interactions.

Finally, peer-review has become a tertiary, yet important, element of support and feedback during the semester-long project. During in-class presentations, students are asked to grade their peers using the same rubrics that the instructors use, and copies are provided prior to the presentations so that students have specific goals to direct their attention. This allows them to “provide constructive feedback on each other’s work”, and peer evaluation is used periodically throughout the semester as part of a “team check-up” to identify problems with team dynamics. The timing and level of this feedback is critical—done too soon, it cannot be used effectively and is seen as “busy work”; done too late, and there might not be enough time to address the issue—and we continue to fine-tune the process each year to maximize its effect.

Principle 7: Metacognition

Metacognition speaks to the ability to step back from the immediate task and evaluate one’s own thinking and learning. Bransford defines *metacognition* as “The process of reflecting on and directing one’s own thinking.”[9] Importantly, this is a distinct skill requiring purposeful development. Ambrose’s principle:

to become self-directed learners, students' must learn to assess the demands of the task, evaluate their own knowledge and skills, plan their approach, monitor their progress, and adjust their strategies as needed.

Each of these five noted skills is indispensable for self-awareness and self-direction in learning, and indispensable in the modern engineering environment. According to Ambrose, the research significantly notes, “Students who were taught or prompted to monitor their own understanding or to explain to themselves what they were learning had greater learning gains relative to students who were not given any monitoring instruction.”

Design-implement projects are time intensive, and class hours devoted to the messy phases of project work are hours not devoted to new content. “I don’t have time for projects” is a common obstacle to their adoption. Yet, it’s in that messy project context that students must muddle through their understanding of the task, confront gaps or misconceptions in their knowledge, strategize approaches to back-fill those gaps or apprehend new material, defend their progress to teammates, and re-adjust strategies as deadlines loom and pressures build. Principle 1 above spoke to prior learning and the dissonance of faculty expectations and student presumption. In a project context, students confront their misconception or shallow learning.

Ambrose’s general prescription: “students will often need our support in learning, refining, and effectively applying basic metacognitive skills. To address these needs then requires us as instructors to consider the advantages these skills can offer students in the long run and then, as appropriate, to make the development of metacognitive skills part of our course goals.” This goal fits neatly with project-based learning and reflects learning outcomes explicitly found in the CDIO syllabus (particularly 2.1- Analytical Reasoning and Problem Solving, 2.2- Experimentation and Knowledge Discovery, and 2.3- Personal Skills and Attributes).[2]

Assessing the Task at Hand

Students commonly enter engineering assuming that problem solving in engineering will resemble the closed-form problem solving they performed in pre-requisite science classes. “Given XX, find YY.” The transition from competent science student to competent engineer will entail weaning them, and progressively setting before them tasks with increasing ambiguity, and multiple solution paths. Early courses can provide more structured tasking and deliverables, whereas upper-class courses could deliberately refrain from explicit detail. The charge would be that students recognize that they must answer specific detailed questions, but the senior should be able to thoughtfully compose the questions they’re to either answer themselves, or draw from their project sponsor or client in negotiation. A sophomore project might explicitly list the questions to be answered; a junior project might flesh out the tasking as a class exercise; a senior project would leave evident questions unstated, expecting the student or their teams to ascertain the detail.

This process Ambrose describes as *scaffolding*, and appears to suggest its use in the context of individual courses. However, scaffolding is particularly well suited to a program perspective on such tasks a technical writing, teamwork, and experimental studies, and should be regarded as a substantial tool for addressing CDIO Standard 3- “Integrated Curriculum.”[2] Scaffolding may successfully be applied to many of our metacognitive skills. For example, the Naval Academy’s aerospace program embeds technical writing instruction in a series of disciplinary courses where the three-year progress begins with structured technical writing assignments through more advanced assignments with less explicit structure, and culminating in senior-level writing assignments with deliberately vague guidance at points. The student is compelled to stand on their own, evaluating the audience and message, and tailoring the writing product accordingly. Moreover, they’re told that the guidance is deliberately vague, and that they’re being conferred responsibility for determining the appropriate scope and detail for their writing products. Hence, the scaffolding is progressively removed over six semesters’ time.

Rubrics provide another means by which students can be boosted towards better assessment of the task, as well as the later task of monitoring their own progress. A variety of CDIO collaborators have been involved in the development and publication of rubrics suitable to project based learning.[10] This also supports and facilitates the targeted feedback described above in Principle 2.

Evaluating Strengths and Weaknesses

The tendency of students to overestimate their understanding is well-documented. The dissonance found in Principle 1 above frequently emerges from a student believing that knowledge at level 2 on Bloom's taxonomy represents mastery, whereas their professor, expecting level 4, regards them as clueless. For the maturity level we seek from a graduating engineer, they need not only formative assessment, but a means by which they can assess their own knowledge mastery. Rubrics, mentioned above, can address this purpose, as can deliberate programmed peer-review of student work. Practice in evaluating the quality of their peers, can be expected to promote better self-reflection. Healthy teams will naturally engage in self-reflective processes gauging one another's work. Those whose work efforts are more polished will commonly place pressure on other team-members to bring their work up to team norms, or lagging team-members will be self-conscious of the disparity in their presented work in team presentations. That self-consciousness of the quality of a student's own work is exactly what we want to promote.

Planning an Approach

An interesting feature of the expert-novice studies reviewed by Ambrose (such as [9]) includes the disparity in time allocated by experts to planning their work. Experts solve problems faster than novices, but spend considerably more time proportionally to their planning of the approach. Students need explicit instruction in how to plan their work. Those who've taught computer programming to undergraduates will have seen this in the habit of students to jump right into typing code without having thought about the structure of the data that they'll need at the end of the problem, or the natural breaks in the program, or the loci at which they might assess the program's accuracy. On larger scales, project planning is explicitly found in the CDIO syllabus within objective 4.3- "Conceiving and Engineering Systems."

Ambrose specifically suggests three practices commonly found in larger-scale projects such as capstones. Her suggestions are themselves scaffolded, to expose the student to the process of planning their work:

- have students implement a provided plan
- have students create their own plan for their work
- make planning the central goal of an assignment

Here's a point at which many project oriented programs could improve, as project planning elements are commonly described in the context of capstone projects in the senior year, but likely not treated previously. The sequence above lends itself to progressive complexity year-to-year in a majors program, where planning skills were explicitly introduced, taught, and utilized over a multi-year program, much as described above for technical writing. Few engineering enterprises succeed for long absent good enterprise and project planning. This is a validated professional skill, which needs nurtured in undergraduates, and valued by faculty. [11]

Applying Strategies for Monitoring Performance

A critical feature of learning to plan their work is that the plan becomes a yardstick for measuring performance. Industry understands this. Budgets are built and real spending compared to projected. Cost and schedule variance are key management measures in most

engineering enterprises. Students need to see the value of even the simplest project plans in monitoring and adjusting their work. Rubrics and peer-review, as discussed above, are vital tools and attributes of project learning, particularly those involving teams. Additional tools addressing this challenge can be found in Koster. [12]

Reflecting on and Adjusting One's Approach

In this section, Ambrose's direct suggestions are contextualized for a traditional lecture course with exams for summative assessment. Yet, the value of this skill is no less applicable to the design-implement experience. We'll highlight two.

"Students should be led through activities that require reflection on their performance." An error we've all committed is packing a short duration project at the end of the term, and allowing a report, competition, or presentation to close the semester. A substantial learning opportunity is forfeited if students individually and as teams are not compelled to reflect on both the quality of their work, *and* all the processes that got them there, to include technical and organizational factors. In the midst of a design team's dysfunction, the pressure to deliver the report on time masks the lesson to be learned about team behaviour. Only absent the deadline can the team more dispassionately glean what they're to learn about the process of making teams work. Early design decisions may have committed them to paths that closed viable alternatives. Those alternatives could now be contemplated for their strengths and weaknesses, in retrospection. In year-long design courses, this activity occurs more naturally provoked by faculty submitting grades for the first semester. For example, a preliminary design review followed by a critical design review allows students to change designs with a slightly different system to achieve the same outcome but more efficiently or at lower cost and labor.

"Create assignments that focus on strategizing rather than implementation." This offers intriguing opportunity for the engineering educator. One particular modern challenge is getting students (and some faculty) to develop *systems perspectives* on engineering design. The systems engineering challenge is particularly keen at the interfaces where a design critically interacts with other systems over which the design team might have no control (the internet, the air traffic control system, GPS, etc.). Implementation projects (Design-build-operate) must necessarily fit within the scope of the time and resources of the academic year and the campus infrastructure (people and facilities). Conceive projects however, short of detailed design, can be of tremendous breadth, while limited scope, with an analysis of alternatives, and can be scaled to fit the time, while fostering the development of a broader systems perspective. Examples might include risk reduction approaches for a vehicle test, analysis of alternatives for landing on the moon, or the air-defense system for a nation's capital. These strategy designs can focus on the Conceive phase, permitting students to more immediately see their ultimate need to understand the societal or business contexts in which they'll ultimately work.

In her 2007 plenary address to the CDIO conference at MIT, Susan Ambrose explained that weak metacognition was characteristic of this particular generation of students.[13] Project-based learning appears an effective medium for tackling this thorny goal of education. John Henry Newman in *The Idea of the University* keyed on metacognition as the very point of the liberal education, "The man of developed [mental] faculties has command of others' knowledge. The man without them, commands not his own." [14] If that was a true and desired aim of education in 1852, how much more so now?

The Other 3 Principles

We've neglected three of Ambrose's principles not because they do not pertain, but rather because we felt the four above most deserved discussion. Of the three that remain, the first two connect with project-based learning so strongly as to be almost self-evident.

- **students' motivation generates, directs, and sustains what they do to learn.**

Sceptics of project-based learning commonly assume that student motivation is the dominant reason for other faculty members' enthusiasm. Motivated students certainly motivate faculty. Our goal here has been to substantiate the pedagogical foundation for project-based learning as far more profound than simply making engineering fun for students. Though, we won't be embarrassed to enjoy ourselves when students have fun while learning.

- **to develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they've learned.**

The principle of Mastery virtually screams for project-based learning, particularly that spanning multiple semesters such as found in the integrated curriculum sought by CDIO programs (CDIO Standard #3).

- **Students' current level of development interacts with the social, emotional and intellectual climate of the course to impact learning.**

This last may deserve a future paper of its own, as we believe project-based learning leverages the multi-dimensional development of the undergraduate, fostering much more than their intellectual development.

CONCLUSIONS

The CDIO consortium has struggled to substantiate our zeal for project-based learning with research quality evidence that our pedagogy works better than that which we seek to reform. Susan Ambrose and her colleagues have provided those interested in improving teaching with substantiation and instantiation of means by which the learning sciences can be brought directly to bear on college teaching and learning. We've briefly considered their distillation as it applies to the project-based learning as embraced by CDIO programs. Our foundational hope is that our peers would consider their work seriously, and join with us in working out together the implications for our programs and our teaching.

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A comparison of strategies to encourage regular study and foster deep learning

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ABSTRACT

One of the challenges facing engineers is efficiently using a growing number of sophisticated tools and methods. This requires not only procedural knowledge on how to use them, but conditional knowledge, which determines under which conditions a given tool or method should be used (when, by whom, where, etc.) as well as conceptual knowledge which is necessary for efficient learning and use of tools and methods as well as for knowledge transfer. This paper presents a learning activity devised to improve deep learning of conceptual knowledge. It was implemented in a second year undergraduate compulsory course in mechanical engineering using three different strategies. Students were:

1. asked to draw a map of the course material that was to be covered in the coming week;
2. asked to produce an individual map of the material covered the previous week;
3. given the choice between drawing a map, writing a summary or attending a 10 minute quiz given at the beginning of the lecture, all on the material covered the previous week.

The third strategy proved the most effective. To explain this result, it is hypothesized that motivation played an important role. When students have a better sense of control over their learning – for example, by having a choice of learning strategies and selecting the one which corresponds most to their learning style – their motivation increases. Furthermore, sense of competence was increased for the students who handed in maps or summaries by performing well in the quizzes. These conditions foster a deep approach to learning.

KEYWORDS

learning activity, concept mapping, topic mapping, motivation, deep learning

INTRODUCTION

One of the goals of the CDIO initiative is to educate students who are able to master a deeper working knowledge of technical fundamentals. This paper proposes a learning activity resulting in an increased sense of control and competence, conditions fostering a deeper approach to learning.

One of the challenges facing engineers is efficiently using a growing number of sophisticated tools and methods. This required not only procedural knowledge on how to use them, but conditional knowledge, which determines under which conditions a given tool or method should be used (when, by whom, where, etc.) as well as conceptual knowledge which is necessary for efficient learning and use of tools and methods as well as for knowledge transfer.

This paper pursues two goals, firstly to present a learning activity designed with the purpose of fostering deep learning and secondly to hypothesize on the mechanisms on which the success of the activity lies. The first goal is achieved through the description of a case study while the second relies on research literature.

To better understand the context leading to this study, the next section presents ETS and its student population. It is followed by a short explanation of different forms of graphical knowledge representation, namely mind, topic, concept and knowledge maps. Follows a description of a learning activity devised to foster deep learning and the presentation of results for three different implementation strategies. Finally, an explanation of implementation results is given before concluding.

PRESENTATION OF ETS AND OF ITS STUDENT POPULATION

ETS (Ecole de technologie supérieure) is located in Montreal, province of Quebec, Canada. It was founded in 1974 at the bequest of industry and until 1989, it graduated technologists. Since then, it has been transformed in a fully accredited engineering school and now offers seven undergraduate programs (mechanical, electrical, construction, automated production, operations and logistics, software and information technology engineering).

To fully understand the context, a few words about the Quebec education system is necessary. The system is organized in 4 levels: primary school (6 years), secondary school (5 years), college (2 or 3 years) and university. In college, students can choose between general (natural, administrative or health sciences, arts and humanities) or vocational technical training. Upon completing college, students who followed the general track normally enter university and those with technical training normally join the work force.

The following statistics characterize our student population:

- over 85% graduated from professional college. ETS is the only engineering school or faculty in Quebec which caters to this student population. It shares this feature with only one other school of faculty in Canada (Ryerson Polytechnic). The remaining 15%, coming from general college, must undergo 1 year of technical training before entering our regular engineering programs;
- 13.5% of students hold a full-time job and study on a part-time basis;
- roughly 80% work on a part-time basis at least 15 hours per week;
- about 25% of students enter ETS after at least 2 years spent working full time as a technician.

All undergraduate programs at ETS possess the following characteristics:

- **strong emphasis on the practical aspects of engineering.** The school favors the acquisition of knowledge and skills through experimentation. All courses offered at ÉTS include two to three hours of laboratory or practical assignments per week. This much contact time devoted to practice is unique among engineering training programs in Quebec;
- **mandatory co-op workterms.** All bachelors-level programs include three mandatory work terms in industry, the last of which must strongly emphasize design. In 2010, ÉTS students carried out over 2000 paid work terms in over 900 companies. In addition, the School offers the possibility of doing an optional research-oriented fourth work term.

ETS is a state university and does not apply a selection policy upon entrance other than verifying that candidates have completed college or demonstrate the equivalent. At the beginning of the 2010-2011 academic year, 3700 students were registered at ETS in an

accredited engineering program. Over 700 students graduate from ETS each year, making this institution one of the five largest engineering schools or faculties in Canada.

The student population profile confers a number of teaching challenges:

- prior training is strongly geared towards procedural knowledge. A proportion of the student population resists acquisition of conceptual knowledge or have not developed efficient learning strategies to deal with this type of knowledge. More often than not, this is voiced by the question: *What is the recipe?*
- personal observation leads to believe that most students at ETS learn by induction rather than deduction, preferring building generalizations from a number of specific cases, moving from a set of specific facts to a general conclusion, from examples to theory. According to Kolb's model of learning styles [1], they would be considered as Accommodators as they prefer to use concrete experience and active experimentation. They are good at actively engaging with the world and actually doing things instead of merely reading about and studying them. This reveals to be a true challenge as classical text books are structured deductively. It is further hypothesized that most professors favour other learning styles and fail to adapt their teaching strategies, favouring strategies with which they themselves feel comfortable.

GRAPHICAL REPRESENTATION OF KNOWLEDGE

Mapping has been proposed as a means to promote deep understanding [2, 3, 4]. Different techniques and tools can be used to represent knowledge, ranging in complexity and subtlety. At one end of the spectrum, one finds mind maps followed by topic maps, concept maps and finally knowledge maps.

Mind maps are graphical representations where secondary ideas irradiate from a central idea, thereby forming a constellation of spokes. Ideas form nodes from which new nodes are formed. Another characteristic of mind maps is the spontaneity with which they are formed. They are therefore often used during brainstorming activities or to rapidly capture and categorize ideas.

When mind maps form networks, they become topic maps, revealing richer connexions between ideas. They share this characteristic with concept maps. Developed by Novak in the 1970's [2], a concept map aims at answering a central conceptual question (What is the finite element method? What is a nonlinear equation? etc.) through a network of concepts, represented by nodes. Nodes or concepts are related to one another by linking words, often verbs. Two nodes and a link form a proposition. One of the difficulties of concept mapping is finding the proper words to link concepts necessary to build these propositions. As the name implies, concept maps are used to represent conceptual knowledge.

Knowledge mapping is even more complex as it is used to represent different types of knowledge (factual, conceptual, procedural, conditional) [3]. A given network often contains different types of knowledge which can be distinguished by different shape of boxes and relationships between knowledge entities form a grammar. For example, conditional knowledge regulates procedural knowledge. Concepts are used as inputs or form outputs of procedures. Facts are instantiations of concepts. Significant training is necessary to create meaningful knowledge maps.

CASE STUDY

The case study concerns a second year undergraduate compulsory course in mechanical engineering. Entitled "Computer assisted engineering", the goal of this course is to gain theoretical and practical knowledge in the use of numerical methods for solving problems

represented by linear and non-linear partial differential equations. Students are thus exposed to finite elements, finite differences and a variety of linearization methods. Each week, students are offered three hours of lecture and exercises during which theory is presented and three hours of laboratory during which they learn MATLAB and ANSYS, a finite element software. Theoretical and practical knowledge are integrated in three mini-projects. An example of a finite element project is to design and dimension a lifting device to extract motors from vehicles.

Adaptation of teaching and learning strategies

An example of how the teaching strategy was adapted to the preferred student population learning style resides in how the mini-projects were introduced. Classically, a professor will teach the theory in class and examples solved with a teaching assistant later in the week. After all or most of the theory is covered, students are assigned a more complex problem to be solved as part of a project. However, in this course, the sequence was reversed. One of the first activities at the beginning of the semester was to hand out the three mini-project statements. Students were asked to discuss strategies and knowledge required to solve the problems. The result of this discussion was related to course material. Every week, links were made between theory and the problem at hand.

This strategy was certainly useful to heighten interest for theory as it was now rooted in a practical problem. However, after giving the course two semesters, it became apparent that, while students picked up the procedural knowledge quite readily, they lacked depth in conceptual and conditional knowledge. Furthermore, many students mentioned that they were fooled by the ease with which they could follow the lectures and baffled when it came time to study for exams or even apply the knowledge in the mini-projects, revealing lack of understanding.

To redress these problems, a new learning activity was introduced in the course. It aimed at encouraging regular weekly study. Each week, every student was asked to produce an individual proof of study. Each proof was marked and students could accumulate a maximum of 10 points over the semester.

Over three semesters, three different strategies were used. In an effort to improve the acquisition of conceptual and, to a lesser degree, conditional knowledge, students were:

1. asked to draw a topic map of the course material that was to be covered in the coming week;
2. asked to produce an individual topic map of the material covered the previous week;
3. given the choice between drawing a map, writing a summary or attending a 10 minute quiz, composed of 5 multiple choice questions on conceptual and conditional knowledge, given at the beginning of the lecture, all on the material covered the previous week.

Topic mapping was selected over mind mapping in order to encourage the emergence of networks, without the formal requirement of having to create propositions as in concept mapping. Knowledge mapping was set aside because of its great complexity.

Qualitative results of regular study strategies

For the moment, no quantitative results as to the effectiveness of these strategies is available. However, changes in attitudes and level of active involvement in the classroom was observed. These qualitative changes are presented for the three different strategies.

Strategy #1: topic map of upcoming course material

This strategy proved to be the least successful. The first few weeks, the resulting maps were average as some students could relate new material to material covered in previous courses. However, as time drew on, it became quickly apparent that they had more and more difficulty linking new knowledge to knowledge covered in previous weeks as evidenced by most maps taking the form of a tree mimicking the reference material chapter subtitles.

Strategy #2: topic map course material covered the previous week

A second strategy was tried the next semester. Every student was asked to produce and hand in an individual map of the material covered the previous week. This strategy was much more efficient. It achieved the goal of maintaining a constant study pace and more students were able to produce meaningful maps as demonstrated by the quantity of concepts presents in the maps as well as the number and quality of links between the concepts.

Four weeks into the course, an informal assessment of how students appreciated the course was conducted. They were asked to write down three items they enjoyed about the course and three items they would like see changed. Out of 54 students, 8 students mentioned that they appreciated the concepts maps, 3 that they didn't mind either way or 6 that they preferred not having this activity. For the rest of the class, it did not appear to be a major issue.

Upon discussion, it became apparent that some students had difficulty drawing the maps, possibly because it did not appeal to their learning style. Furthermore, it was deemed not sufficiently strategic for another group, in the sense that they could not see how it helped them obtain better marks at exams and therefore did not judge it was worth the time spent drawing the map.

Strategy #3: choice of topic map, summary or quiz

Students were given the choice between drawing a map, writing a summary or attending a 10 minute quiz given at the beginning of the lecture, all on the material covered the previous week. Quizzes were composed of 5 multiple choice questions on conceptual or conditional knowledge.

Results were quite surprising. Out of 33 students, 24 students handed-in topic maps and 2 wrote summaries. Most topic maps contained concepts and few procedures. All students attended the 10 minute quiz. However, the 7 students who neither handed in the maps nor the summary systematically had the worst results by the end of the semester. Two of them ended up abandoning the course.

This third strategy proved the most effective in terms of student acceptance. There were no more complaints about having to hand in a weekly assignment. If student interaction during lectures is construed as evidence of deeper learning, this strategy was also the most effective in terms of deep knowledge acquisition. The number and quality of questions asked by students during lectures as well as the readiness with which they performed active learning tasks during class far surpassed those observed with the first two strategies.

EXPLANATION OF SUCCESS

Novak and Gowin [2] contend that approximately 5 to 20% of students respond negatively to instruction that requires meaningful learning and will resist strategies such as mapping, while about the same percentage are enthused by such strategies.

The results in this study showed that acceptance varied greatly with implementation strategy. Acceptance was even lower than expected compared to Novak and Gowin's claim for the first strategy, about the same for the second and much higher for the third.

To explain these results, we turn to the theory of motivation. If intrinsic motivation is an essential condition for deep learning [5], the next question becomes: what are the conditions that foster intrinsic motivation? Viau [6] teaches us that three factors influence student motivation, based on their perception of :

1. the value of a learning activity,
2. their capability to accomplish the task,
3. the control they can exercise on the task at hand.

Table 1
Characteristics of three implementation strategies with respect to motivational variables

Strategy	Motivational variables		
	value	capability	control
1- Mapping of upcoming material	low	low	low
2-Mapping of past material	medium	medium	low
3-Mapping, summary or quiz	high	high	high

With implementation strategies 1 and 2, students were given no choice other than handing in an individual map, giving them a low sense of control over the activity. When given the choice, students could select the tool they most felt suited their learning style, heightening their sense of control.

In the third strategy most students elected to hand in either a map or a summary **AND** perform the quiz. These students systematically had a mark of 4/5 or more, where as the students who chose to perform only the tests did poorly. These results surely increased the sense of competence of those who studied regularly and encouraged them to pursue with this learning activity. It also surely played a role in their perception of the value of the activity in that not only did they perform well in weekly tests, but they also could follow and participate more actively during lectures, thereby reinforcing their perception of capability.

Mapping of upcoming material proved too difficult, affecting the perception of capability downwards. Furthermore, because it did not seem to help them in anyway, students did not value it. This was somewhat alleviated by mapping past material, where students had a better grasp of the content but a number of students resisted the method of knowledge representation.

CONCLUSION

This paper presented a learning activity devised to encourage regular study and foster deep learning. It consisted of handing in a proof of study on a weekly basis. Three implementation strategies were tested. The third strategy, whereby students were given the choice to either hand in a topic map, a summary or attend a 10 minute quiz proved the most effective in terms of student acceptance and acquisition of knowledge.

One of the irritants of all three strategies employed resides in the fact that the assignment was to be done individually. An improvement over existent strategies would be to offer students the possibility to produce a collective concept map.

One limitation of the current study is that it is mostly qualitative in nature. However, the experience is considered sufficiently significant to warrant further study for which metrics or instruments should be devised for a more robust research protocol. The type of maps (topic vs concept maps) handed in, as well as the analysis of their content structure (spoke or radial organization, chain structure or networks [7]) are potential metrics.

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Biographical Information

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Peer Instruction method in introductory Math courses

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ABSTRACT

Learning is not a spectator's sport. Students do not learn much by just sitting in class listening their teachers, memorizing pre-packaged assignments and spitting out answers.

The teaching-learning process has been a constant target of studies, particularly in Higher Education, in consequence of the annual increase of new students. The concern with maintaining a desired quality level in the training of these students, conjugated with the will to widen the access to all of those who finish Secondary School Education, has triggered a greater intervention from the education specialists, in partnership with the teachers of all Higher Education areas, in the analysis of this problem.

Considering the particular case of Engineering, it has been witnessed a rising concern with the active learning strategies and forms of assessment.

Research has demonstrated that students learn more if they are actively engaged with the material they are studying. In this presentation we describe, present and discuss the techniques and the results of Peer Instruction method in an introductory Calculus courses of an Engineering Bach.

KEYWORDS

Peer Instruction, calculus, teaching-learning process, learning strategies, assessment.

I - INTRODUCTION

Learning is not a spectator's sport. Students do not learn much by just sitting in class listening their teachers, memorizing pre-packaged assignments and spitting out answers.

The teaching-learning process has been a constant target of studies, particularly in Higher Education, in consequence of the annual increase of new students. The concern with maintaining a desired quality level in the training of these students, conjugated with the will to widen the access to all of those who finish Secondary School Education, has triggered a greater intervention from the education specialists, in partnership with the teachers of all Higher Education areas, in the analysis of this problem.

Considering the particular case of Engineering, it has been witnessed a rising concern with the active learning strategies and forms of assessment.

Research has demonstrated that students learn more if they are actively engaged with the material they are studying. In this presentation we describe, present and discuss the techniques and the results of Peer Instruction method in an introductory Calculus courses of an Engineering Bach. This course has over 500 students, a little over half of them repeating. Students' motivation to attend the course is probably the lowest among all of the program's courses. Thus the need arose to apply a new learning method that would result in a positive change in students' attitude towards the course.

This paper is structured as follows. Peer Instruction is described in Section II. In Section III, we present the used techniques and in Section IV the assessment results.

II - PEER INSTRUCTION METHOD

Peer instruction (PI) was developed in the 1990's at Harvard University by Eric Mazur. It has become a successful interactive teaching method in physics [2, 6]. PI is gaining popularity in calculus classrooms but there is limited documentation about its effectiveness [8, 7].

In this method,

- The teacher presents students with a qualitative (usually multiple choice) question that is carefully constructed to engage student difficulties with fundamental concepts.
- The students consider the problem on their own and contribute their answers in a way that the fraction of the class giving each answer can be determined and reported.
- Students then discuss the issue with their neighbours for two minutes and vote again.
- The issues are resolved with a class discussion and clarifications.

This method, besides having the advantage of engaging the student and making the lecture more interesting to the student, has the tremendous importance of giving the instructor significant feedback about where the class is and what it knows.

To often, we use the "union of knowledge principle" -- if any student in the class knows something, we assume the whole class knows it. The response system gives us much better information about the distribution of knowledge among our students. This method also offers significant opportunity for engaging the students in discussions of reasoning and epistemology (how we decide which answers are right and under what circumstances the answers hold).

III – TECHNIQUES

Data sources included classroom data show, a white board and “fingers” (no clickers).

There were 558 students enrolled in 10 small sections of 50 to 60 students. These small sections were taught by 3 different lecturers.

As a large number of our students are working student and not have much time to study at home. At the beginning of class, the



first 30 minutes, the lecture did an extensive summary of the subject.

The next 20 minutes were dedicated to the PI method. Some multiple-choice questions are presented to the class and the lecture gives a few minutes for the student to give their answer. The students think by themselves and register their vote. After this, the lecture asks the students to discuss the issue with their neighbours, preferably a student who gave a different answer.

If the lecture put the following question:

- 1- Find the area shown shaded in the diagram, bounded by the **y**-axis, the line $y = 3$ and the curve $y = x^2 + 2$

Answer:

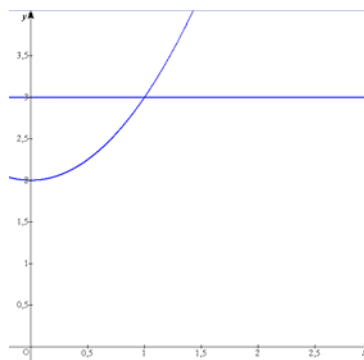
a) $\int_0^1 (x^2 + 2) dx$

b) $\int_2^3 (x^2 + 2) dx$

c) $\int_0^1 3 - (x^2 + 2) dx$

d) $\int_0^1 3 dx$

e) None of the above



Some of the questions the students make to their neighbours would be:

“What you answered? “, “Why?“, students share their reasoning and their math knowledge for four or five minutes and vote again.

With the question we present to students we assess whether student have learned the lecture objectives.



III – ASSESSMENT RESULTS

Table 1 presents the results of the Calculus course since school year 2006/2007; the year ISEP programs adopted the Bologna format. Over 50% of the program’s students are typically enrolled in this course, making it the course with most students in the program. The results are detailed for new students and re-enrolling ones, the last ones being the majority.

Table 1
Summary of the Calculus course results since 2006/2007

Year	Students	Succeed	Fail	Abandon	Total
2006/07	New	32	53	132	217
	Re-enrolment	141	40	232	413
	Total	173	93	364	630
2007/08	New	50	97	73	220
	Re-enrolment	72	84	237	393
	Total	122	181	310	613
2008/09	New	93	90	50	233
	Re-enrolment	93	33	224	350
	Total	186	123	274	583
2009/10	New	75	66	89	230
	Re-enrolment	81	36	206	323
	Total	156	102	295	553
2010/11	New	148	31	39	218
	Re-enrolment	163	34	143	340
	Total	311	65	182	558

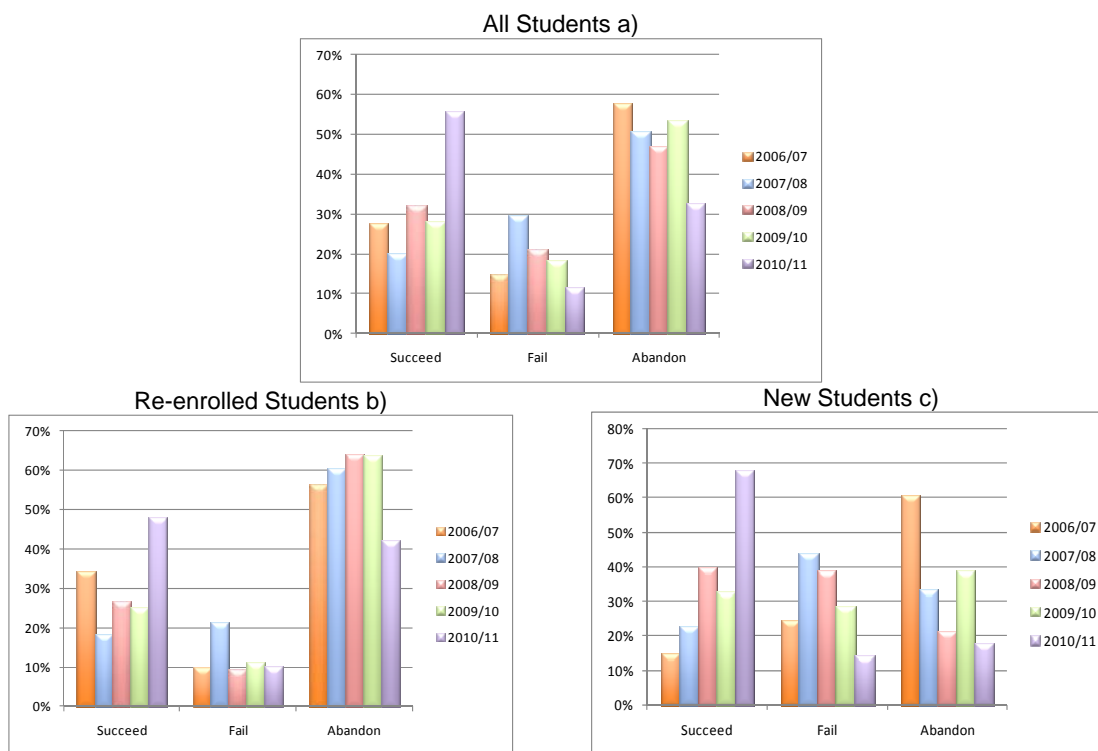


Figure 1. Results per "type" of Students

Figure 1 depicts the evolution of the course's results per type of student. The school year 2006/2007 results were extraordinarily bad for new students. The results for this group have been improving steadily over time, though always below the 40% success rate. On the other hand, re-enrolling students results have been deteriorating over time, albeit slowly. The major cause of failure for both new and re-enrolling students is abandon, i.e. the students stop attending classes and don't do the exams.

The PI approach was introduced in school year 2010/11 and the overall success rate increased dramatically to a little over 50%. This increase did occur not only for new students, but also for

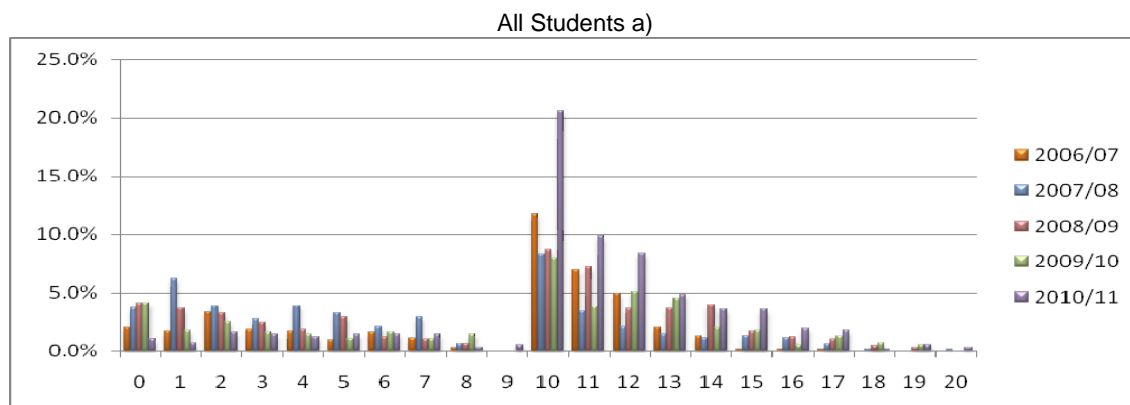
re-enrolling ones, which increased from 30% to 48% Figure 1b). This increase was due to the decrease in the number of students who abandoned the course, as shown in Table 1 and Figure 1a). In fact, the number of the student who abandoned the course was nearly halved. The same happened for new students, as depicted in Figure 1c). To better understand what happened, the actual grades are depicted in Table 2 and in Figure 2. The grades are presented in the [0; 20] grade scale used in Portugal. Students pass with a grade of 10 or more.

Table 2
Grades ([0; 20] grading scale, pass at 10)

Year	Students	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2006/07	New	9	9	12	7	7	3	4	2	0	0	17	3	8	2	1	0	0	1	0	0	0
	Re-enrollment	4	2	9	5	4	3	6	5	2	0	57	41	23	11	7	1	1	0	0	0	0
	Total	13	11	21	12	11	6	10	7	2	0	74	44	31	13	8	1	1	1	0	0	0
2007/08	New	17	21	14	9	12	10	8	6	0	0	21	12	4	1	3	3	2	3	0	0	1
	Re-enrollment	6	17	10	8	12	10	5	12	4	0	30	9	9	8	4	5	5	1	1	0	0
	Total	23	38	24	17	24	20	13	18	4	0	51	21	13	9	7	8	7	4	1	0	1
2008/09	New	19	15	15	10	11	11	6	2	1	0	26	16	14	10	11	5	5	5	1	0	0
	Re-enrollment	5	6	4	4	0	6	1	4	3	0	25	26	7	11	12	5	2	1	2	2	0
	Total	24	21	19	14	11	17	7	6	4	0	51	42	21	21	23	10	7	6	3	2	0
2009/10	New	23	6	9	7	5	4	6	3	3	0	20	10	14	14	5	5	1	3	2	1	0
	Re-enrollment	0	4	5	2	3	2	3	3	5	0	24	11	14	11	6	5	2	4	2	2	0
	Total	23	10	14	9	8	6	9	6	8	0	44	21	28	25	11	10	3	7	4	3	0
2010/11	New	2	1	4	6	3	4	2	3	1	2	47	31	24	14	10	9	4	5	1	2	1
	Re-enrollment	4	3	5	2	4	4	6	5	1	1	68	24	23	13	10	11	7	5	0	1	1
	Total	6	4	9	8	7	8	8	8	2	3	115	55	47	27	20	20	11	10	1	3	2

One first conclusion is that there was an overall improvement in the course's grades in the interval [0; 12]. There was hardly any increase in grades above 13 points. This increase at the low end of the grading scale leads us to conclude that PI may have been responsible for motivating low end students to attend classes and to try to succeed on the course. Many did actually succeed, albeit achieving only low-end results.

This conclusion is supported by student attendance to lectures during the whole semester, which actually rose after the first few weeks. This is completely unheard of at this type of course. The opposite usually happens, with many students stopping attending classes after 4 or 5 weeks. Furthermore, the increase in attendance was mostly noticed in re-enrolling students.



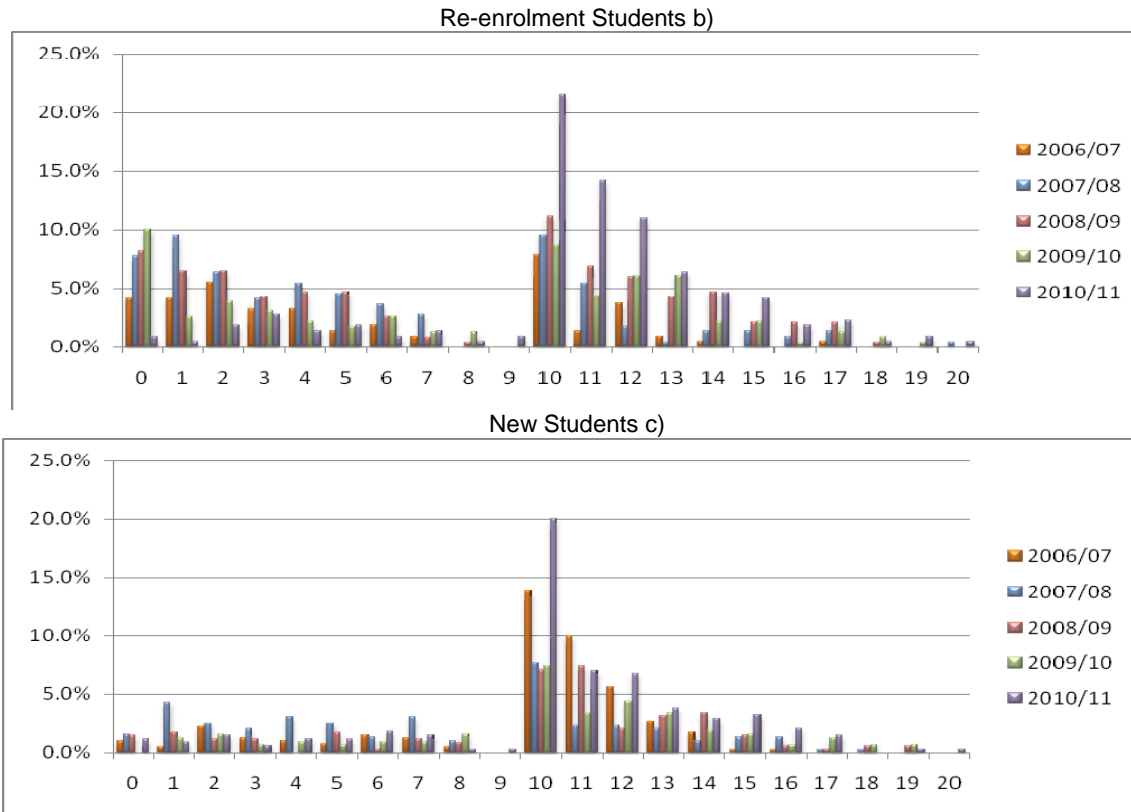


Figure 2. Grades per “type” of Students

The students’ feedback on the PI method was overall positive. The students felt that PI was beneficial to themselves and their classmates. Here we present some student’s comments: “I feel that it teaches more to the students, because we are not hearing a lecture from the same old professor.”; “We were genuinely interested and wanted to share our opinion.”; “Having students (peer teaching) teach gives it a fresh outlook and a creative take on material.”

At the end of the course, a non-mandatory inquiry was made, asking students to evaluate their satisfaction of the PI method implementation, Table 3 . 80.28% answered the PI lessons were more interesting and that they learned more using it than with the traditional lecture method. Only 21.13% said that, regardless of the method used, they would always learn (9.15%) or do not learn (11.97%).

Table 3
Inquire to students (145 answers)

It made the lessons more interesting and I learned more in classes which the method Peer instruction was applied	Doesn` t matter, I learned always	Doesn` t matter, I didn't learn anyway
80,28%	9,15%	11,97%

CONCLUSION

Over half of the students in one of ISEP engineering programs were enrolled in the Calculus course, which had a typical failure rate of 60 to 70%, mostly due to students quitting the course. To address this problem, an innovative approach had to be used in order to motivate the

students to actively participate. Peer-assisted instruction allows students to express themselves, participate in their own learning, and further engage in a course. Thus it was selected to be used in this “problematic” course.

Overall results improved with the PI approach, though mostly at the low end of the scale. PI was thus successful in engaging low-end students to fully participate in the course. Most students praised the atmosphere created through the use peer instruction in lectures.

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A KNOWLEDGE/SKILLS/COMPETENCE DESCRIPTOR BASED GRADUATE GRADING SYSTEM FOR CDIO PROGRAMS

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ABSTRACT

This paper discusses the problem of graduate grading and proposes a descriptor based grading system more suited to CDIO compliant engineering programs. It compliments the cumulative grade point average (used in Portugal) by a set of three descriptors that individually describe proficiency in program Knowledge, Skills and Competence, aiming to improve professional/social recognition of graduates and to facilitate the profiling of those graduates by employers. The proposed solution for the Informatics Engineering bachelor program is based on three distinct categories of curricular units, mapping one-to-one with Knowledge, Skills and Competence. The solution also addresses issues like “engineering is much more than knowing things”, “engineering schools’ diplomas essentially endorse knowledge”, and “employers disregard global grade average indicators”. It can be seen as a natural consequence of CDIO adoption, understandable by stakeholders and simple to operate. Applying the new descriptor based grading system to a significant sample of graduates allowed the identification of a few dominant “graduate stereotypes”, each one with its own balance between Knowledge, Skills and Competence. In the near future we envisage this grading system will help to improve graduate profiling and hiring by employers...

KEYWORDS

CDIO, Informatics, Grades, Grading systems.

INTRODUCTION

The Informatics Engineering 1st Cycle Program of ISEP (Porto School of Engineering) was reformed in 2006 to comply with European Bologna directives. At the same time it incorporated many recommendations and good practices from CDIO [1] like design-build-projects on all curricular semesters, deep learning replacing surface learning, reinforcement of capability/competency oriented curricular activities, and stimulating course and faculty collaboration, just to mention a few. Since 2006-07 three full academic years have passed (2007-08, 2008-09 and 2009-10) and a lot of quantitative program data has been collected [2], suggesting a rigorous evaluation and assessment of the CDIO inspired improvements in the Informatics Engineering Program (LEI). After September 2010 the authors decided to perform systematic data analyses so that CDIO impacts could be studied and conclusions gathered. From the authors’ personal experience as program directors and capstone project managers, it was clear that LEI performance improved since 2006-07 and that graduates have better social and professional recognition. It was even noted that more and more graduates were achieving excellent capstone performances, despite many of them

having low/median academic grades in most of the “conventional” courses. This “phenomenon” was also an important objective to study and understand.

In this paper we describe how access grades, “conventional” program course grades and “CDIO inspired” program course grades relate between themselves, using a sample of 100 LEI students enrolled in 2006-07/2007-08 and graduated in 2008-09/2009-10. From this analysis we identify the weaknesses of using “Cumulative Grade Point Average” (CGPA) [3] techniques as a means to describe the “quality” of graduates, and propose a new descriptor based grading system for individually characterizing graduate proficiency in program Knowledge, Skills and Competence. This alternative graduate grading system, which takes into account the evaluations of capstone project supervisors and external stakeholders, aims to improve the professional/social recognition of graduates and to facilitate the profiling of those graduates by employers.

CONTEXT

In Portugal access to public Higher Education Institutions (HEI) like universities and polytechnics is managed by a national ranking system, in which each candidate student applies up to six programs and has an “Access Grade”, in the 0-200 range, defined by a weighted average of secondary school course grades and final exams encompassing subjects like “Portuguese”, “Mathematics”, “Physics”, etc. As each HEI previously defines the maximum number of new students (*numerus clausus*) for its programs, the sorting and assignment of students to programs is globally performed by a computational system and results are published on a public web site. Since 2006 LEI is having more than three times candidates than placed students, of which more than 60% enrol the program as first option. In spite of those good placement results, LEI is competing for students with the Faculty of Engineering (FEUP) of the best ranked Portuguese university (Porto University). In Portugal the best universities tend to attract the candidates with highest access grades, and that also happens for Informatics Engineering in the metropolitan area of Porto. Figure 1 shows the relationship between access grades and enrolment options for LEI placed students and Figure 2 for the Informatics Engineering Master Program of FEUP (MIEIC-FEUP).

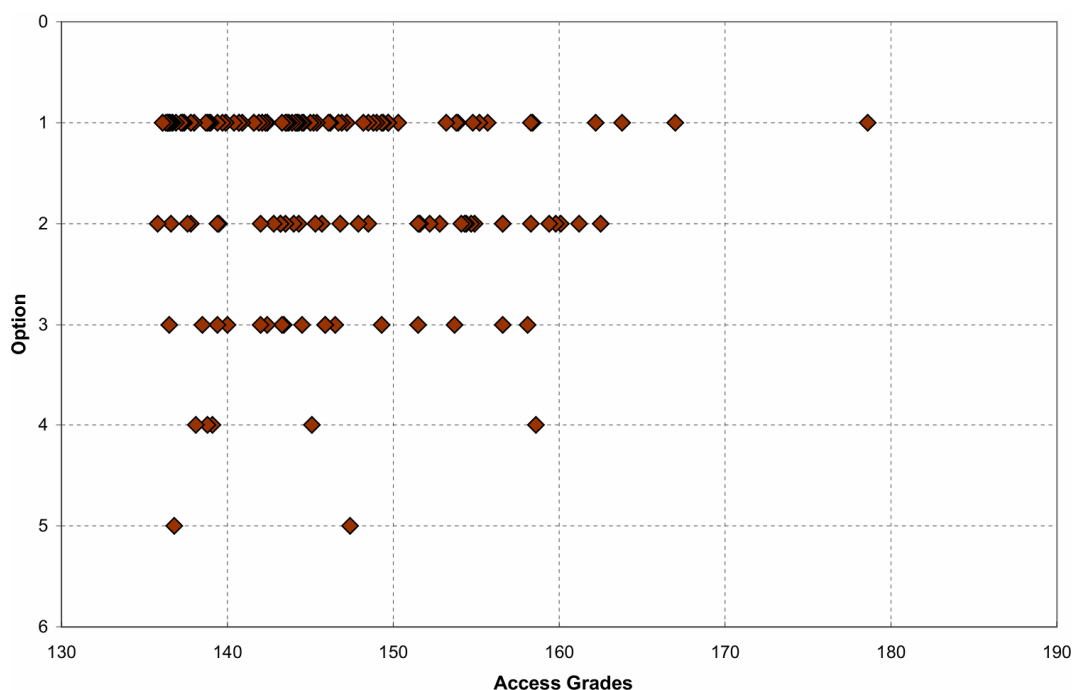


Figure 1. Access Grades x Enrolment Options for LEI Placed Students in 2010-11 (580 Candidates)

In Figure 1 it is clear that most of access grades for LEI placed students are greater than 135 and smaller than 160, with most of placed students enrolling as first or second option.

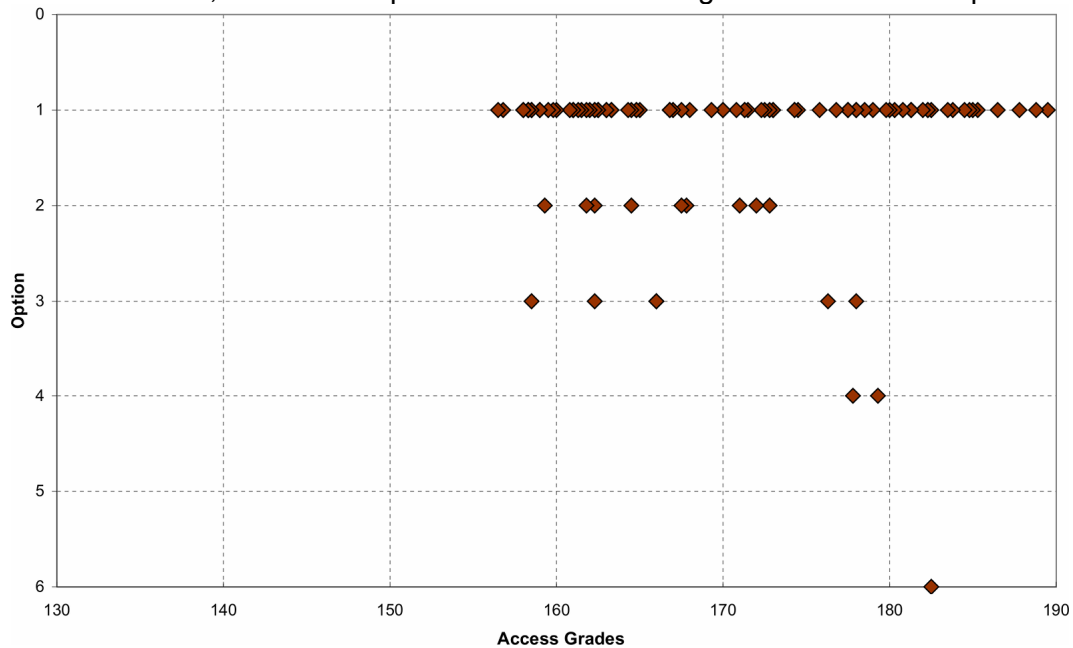


Figure 2. Access Grades x Enrolment Options for MIEIC-FEUP Placed Students in 2010-11 (600 Candidates)

In Figure 2 it is noticeable that most of access grades for MIEIC-FEUP placed students are greater than 160, revealing an obvious stratification between student placement in LEI and MIEIC-FEUP. This stratified student placement means that LEI gets students with lower access grades, less scientifically prepared, but not necessarily having lower potential for becoming competent informatics engineers. This challenging context was already known before 2006 and was a strong motivation to adopt CDIO in the reform and operation of the new LEI [2].

Some of the most important LEI performance indicators are related with the Capstone Projects. Since 2002 most of the Capstone Projects have taken place as internships in external organizations, with very positive feedback from internship supervisors. Table 1 shows the evolution of Capstone Projects proposals and internships per academic year since 2005-06.

Table 1
Evolution of Capstone Projects proposals and internships per academic year

Capstone Project	2005-06	2006-07*	2007-08	2008-09	2009-10	2010-11
Proposals	200	200	200	230	250	300
Internships	70	60	120	140	150	170

* 2006-07 was the transition year to the Bologna reformed LEI

Table 1 shows that labour market response to the new LEI has been positive and keeps improving. In terms of internship results, Figure 3 shows the relative frequency of Capstone Project grades (0 to 20 range). It should be noted that since 2007-08 evaluation of Capstone Projects is performed by a jury which always includes the LEI Program Director and the Capstone course manager, as well as the tutoring teacher and the internship supervisor, in order to guarantee grading comparability in the evaluation process.

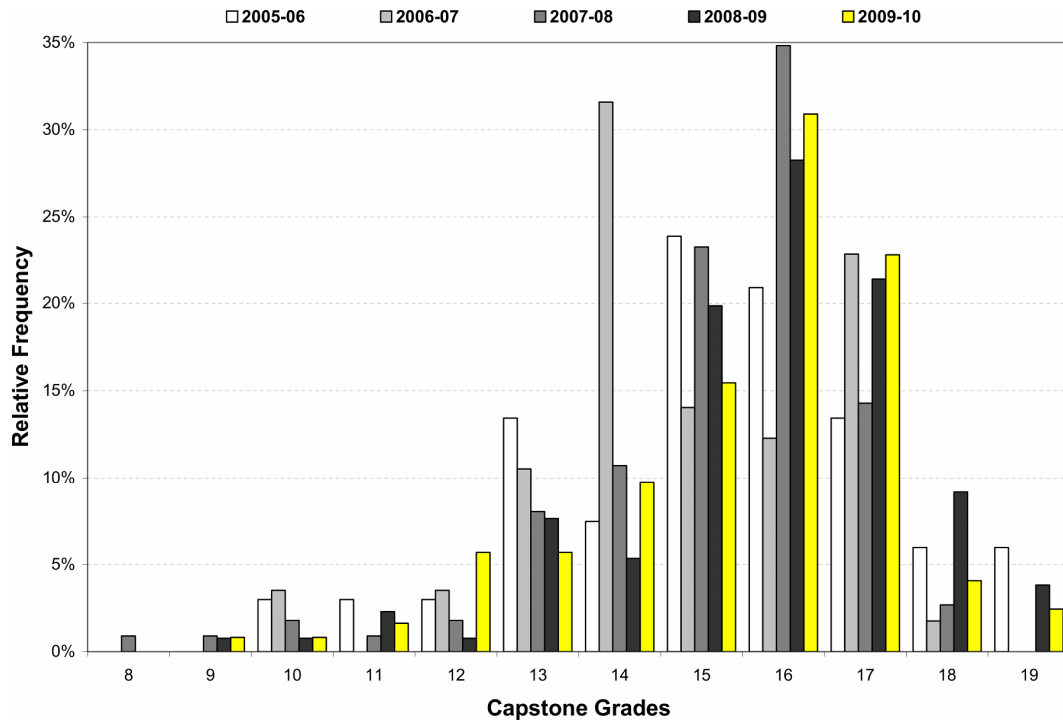


Figure 3. Relative Frequency of LEI Capstone Grades for Academic Years 2005-06 to 2009-10

In Figure 3 we notice that, excluding 2006-07 (the transition year), grade distribution shows a clear and coherent pattern along the academic years. Figure 4 depicts how the internship supervisors evaluate a set of Capstone student skills and competence along several academic years. This evaluation is supported by a written rubric questionnaire that internship supervisors fill during Capstone/internship presentation.

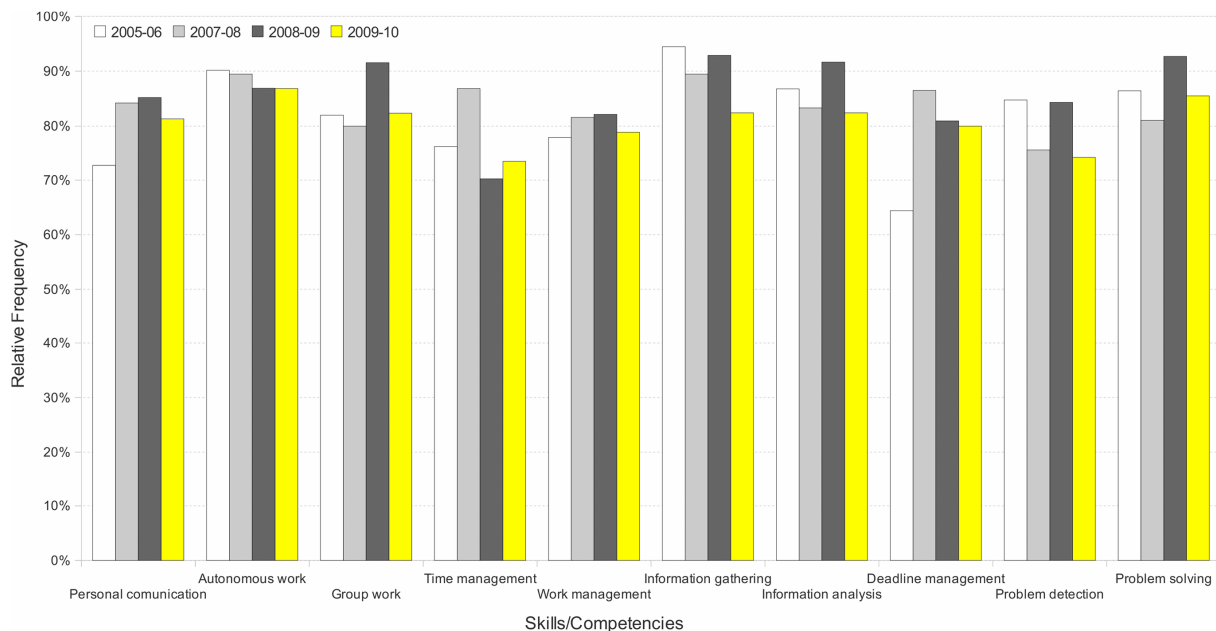


Figure 4. Student Skills/Competence evaluated from inquiries to Internship Supervisors

We observe in Figure 4 that skills and competence variation along the years is less than 20%, except for “Deadline management”, which improved in the new LEI Program. It is also important to say that employability after Capstone Project completion is almost 100%, which is mostly due to students becoming professionally integrated in the internship organization.

In late 2010, three full academic years of LEI past the 2006-07 Bologna transition, it was decided to gather information about students when entering the program and after concluding it. We already knew long ago that the “LEI Grade”, computed as a normalized sum of the ECTS weighted course grades, had low correlation with the Capstone Project grade (typically less than 0.3). Every year many students with low LEI grades managed to achieve very good Capstone Project grades, and most of the times it was quite surprising and thrilling to see how an “average student” transformed into a “very good professional”. Because we had access to placement access grades, LEI course grades and the program grade, a study was developed aiming to shed light on how that data might help understand the student transformation “phenomena”.

Figure 5 depicts the relationships between Access Grades (used for program placement), Math Grades (required final exam for informatics engineering) and LEI Capstone Project Grades (circle diameter proportional to grade).

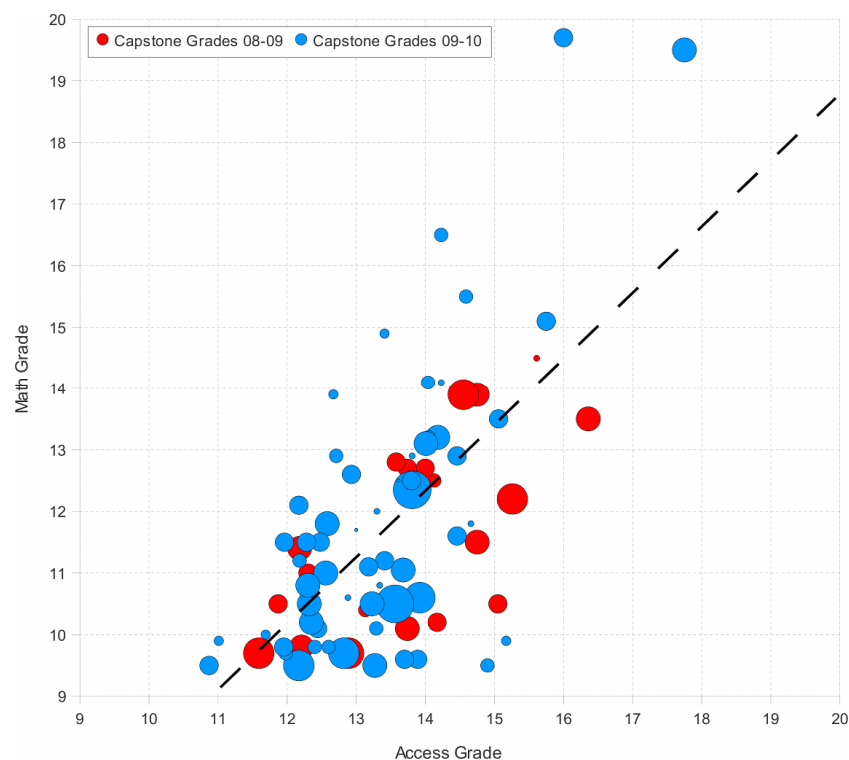


Figure 5. Access Grades versus Math Grades versus LEI Capstone Grades (sample of 100 students enrolled in 2006-08 and finishing in 2008-10)

It is clearly observed in Figure 5 that many students achieved very high Capstone Grades in spite of having low Access and Math Grades at the end of secondary school. There is also a good correlation between Access Grades and Math Grades, as it was expected (the dashed trend line).

Figure 6 relates the Access Grades (for placement), the LEI Program Grade and the LEI Capstone Project Grades (circle diameter proportional to grade). In Figure 6, Capstone Grades have almost no correlation (0.002) with Access Grades, and they have a low correlation (0.49) with LEI Program Grades. Without surprise, the dashed trend line approximates the relationship between Access Grades and LEI Program Grades (correlation 0.46).

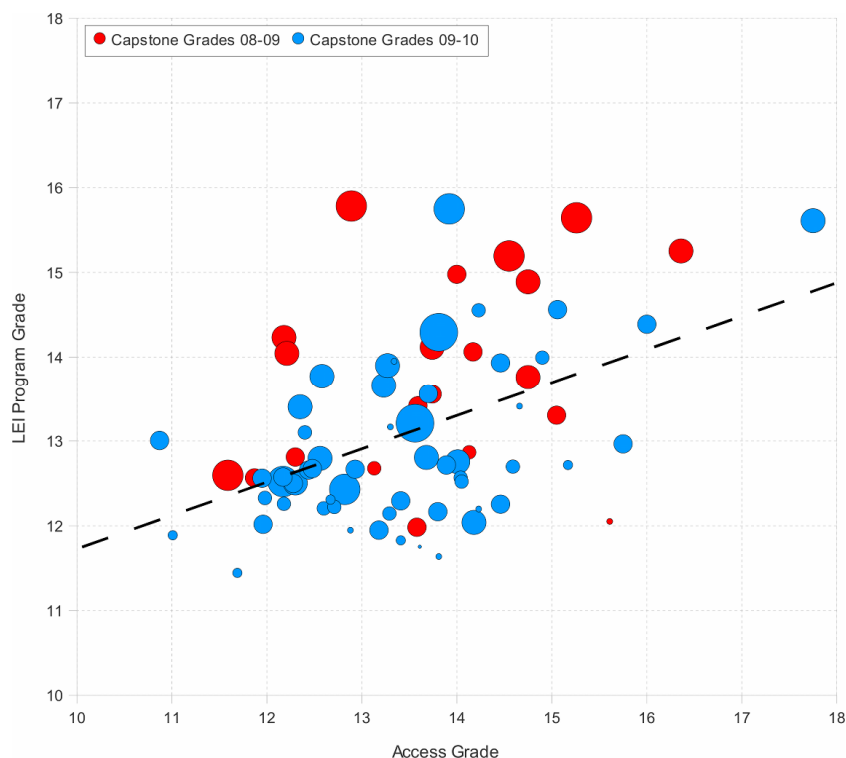


Figure 6. Access Grades versus LEI Program Grades versus Capstone Grades (sample of 100 students enrolled in 2006-08 and finishing in 2008-10)

In synthesis, we have good reasons to believe that the LEI Program, in terms of process and product, has been improving since 2006, with many different evidences contributing and supporting this opinion. At the same time, we believe the use of a Cumulative Grade Point Average approach [3] to characterize the LEI product (program graduates) is not suitable to describe the “quality” of those graduates. Because a Cumulative Grade Point Average grade is just a number resulting from the amalgamation of lots of other numbers, it is not able to efficiently describe any kind of proficiency whatsoever. As such, a better alternative has to be found so that external stakeholders, especially employers, can easily differentiate the graduates and quickly identify the ones most suited to some specific type of work.

A CDIO INSPIRED GRADING SYSTEM FOR THE LEI PROGRAM

Aiming to better describe student’s knowledge, skills and competences using the Syllabus as a reference, in the search for an alternative to the current LEI cumulative grade point average system two main alternatives were identified:

- Learning process based, i.e. describing the student’s proficiency in each of the program’s learning processes;
- Category based, i.e. describing the student’s proficiency in each of the Syllabus’ areas/categories.

Curriculum as a Set of Learning Processes

“CDIO Standard 3 — *Integrated Curriculum: a curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills.*” As implied in CDIO Standard 3, a program must have one or more learning processes (ordered sets of interrelated courses), which provide the student with a set of well-defined skills. The process final outcomes are a subset of the program Syllabus.

Typically the course is the basic entity in the process and a course may belong to several processes. A course has a set of outcomes, which are used for student assessment, and some of those outcomes are directly related to the process or processes it belongs. Nevertheless, one must stress that learning is a complex process, where is not possible to decouple the effects of each course on the student. In fact, it is quite the opposite: a program should be designed in order to provide the student with an integrated learning experience in which the final result should be more than the sum of the parts. The experiential learning model [4], which is the foundation of CDIO, is an example of this: the concrete experiences in design-implement experiences deeply affect the way students learn in the following courses.

In this approach, the program's main "processes" (sets of related courses) must be identified, so that these courses can then be managed in an integrated fashion: each course is a client of the preceding one and a server to the next. The "fitness for use" [5] of the student in one of the process course, fulfilling the courses pre-requisites in terms of real student skills, is directly related to the process quality up to that point. The identification of learning processes is clearly program dependent. Three learning processes were identified in LEI, as depicted in Figure 7:

- Programming and Modelling
- Networks and Computing Systems
- Software and System Engineering

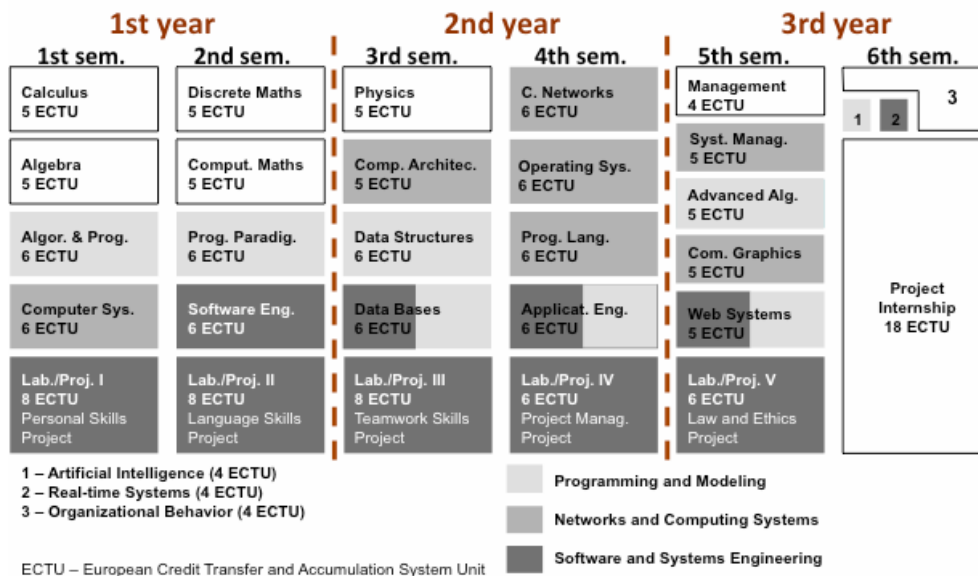


Figure 7. The three LEI learning processes

As shown in Figure 7, some courses belong to more than a process and there are eight courses that are not included in any process. One is the Capstone Project/Internship; the others are the Math, Physics and Management courses. Though some of the Math courses are clearly interrelated, they are support courses and there is no point in defining a process for them.

To grade the graduate's proficiency in each of the three learning processes one could compute the average grade of each process courses and present them in a qualitative scale. But the real question is: does this provide a reasonable estimate of the graduate's knowledge and skills? We do not think so. A process is an important abstraction for quality control within the program [6], but the product's "final quality" is more complex than the proficiency in the several processes' courses. Another issue is that the Capstone Project is not included in any

process and employers often regard it as a very relevant benchmarking tool, even more important than the program's cumulative grade point average.

Curriculum Mapping to a Set of CDIO Inspired Categories of Outcomes

The LEI curriculum has three types of courses:

- Standard, i.e. 12 to 16 weeks course with lectures and lab classes. The assessment usually includes some practical work and a final exam. Subjects range from Math and Physics to Management and Informatics related subjects.
- Lab/Project, i.e. 4 weeks intensive design-build team experience at the end of the semester. Each course also includes a 16 to 20 hours soft-skills module, as shown in Figure 7.
- Capstone Project, i.e. 20 to 30 weeks Project with internship in some organization or a R&D unit.

There is an "official" mapping between these courses' outcomes and the LEI Syllabus, thus one could select the four Syllabus categories as the base for a grading system. Unfortunately, although the mapping is quite good in category 1 (Technical Knowledge and Reasoning), it is far from perfect in categories 2 and 3 (Personal, Interpersonal and Professional Skills and Attributes). Nevertheless, there is a quite good match between the Lab/Project courses plus Capstone Project and category 4 (Engineering Skills, Attributes and Competence).

Fortunately, the European Qualifications Framework (EQF) offers a way to overcome this mapping problem by using three categories of learning outcomes [7]:

- "Knowledge", meaning the outcome of the assimilation of information through learning, where knowledge is the body of facts, principles, theories and practices that is related to a field of work or study. In the context of EQF, knowledge is described as theoretical and/or factual.
- "Skills", meaning the ability to apply knowledge and use know-how to complete tasks and solve problems. In the context of EQF, skills are described as cognitive (involving the use of logical, intuitive and creative thinking) or practical (involving manual dexterity and the use of methods, materials, tools and instruments).
- "Competence", meaning the proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development. In the context of EQF, competence is described in terms of responsibility and autonomy.

Mapping the LEI Curriculum and the three EQF categories of learning outcomes at level 6 (corresponding to the 1st cycle Bologna qualification) was not a simple task, considering what is required at level 6:

- "Knowledge" – *Advanced knowledge of a field of work or study, involving a critical understanding of theories and principles.*
- "Skills" – *Advanced skills, demonstrating mastery and innovation, required to solve complex and unpredictable problems in a specialised field of work or study.*
- "Competences" – *Manage complex technical or professional activities or projects, taking responsibility for decision-making in unpredictable work or study contexts. Take responsibility for managing professional development of individuals and groups.*

Also, there is little to gain from designing a complex mapping between the courses and the three categories. The more straightforward the mapping is, the better it will be understood by employers and graduates. Therefore, we propose the following mapping:

- **Knowledge:** the standard courses, as they are most related to scientific, technical and factual knowledge.
- **Skills:** the Lab/Project courses, as they were designed to provide the students with real engineering skills which they were not able to fully develop in standard courses. Also the personal skills modules and the Organizational Behaviour course fit quite well in this category.
- **Competence:** the Capstone Project, being the course where students are most challenged in terms of realistic professional activity. The Lab/Project courses could also contribute to this category but, as explained before, employers already use the Capstone Project grade as benchmark, so it is reasonable to keep it in a separate category.

Descriptor Based Grading System for LEI Graduates and Employers

Having established the methodology for mapping LEI courses' results and the three EQF based categories, it was decided that a descriptor based solution was the most adequate way to transmit the relevant information in a simple and effective way. As such, an "A-D" qualitative scale was chosen, where A is "Excellent", B is "Very Good", C is "Good" and D is "Sufficient".

The method for determining the qualitative grades for each category is briefly explained:

1. For each of the three categories, a cumulative grade point average is computed using the corresponding courses' grades and the ECTS curricular weights, producing a numerical value in the 10-20 range.
2. Because readability and comparability is very important for employers, it was decided not to use annual percentage quotas to convert from the 10-20 range to the A-D scale (e.g., the 10% best values in each category get an A). Therefore, we had to define numerical thresholds to convert the numbers to the A-D scale.
3. To compute those thresholds (which are very program specific) we resorted to the sample of 100 graduates used to produce Figure 5 and Figure 6. One of our goals was to keep the number of A's no bigger than 10%, so choosing an appropriate A threshold in each of three categories was critical. After having defined the A thresholds, the B/C/D thresholds were easier to determine. Finally, by a detailed analysis of the 10-20 categorical results we were able to define the remaining thresholds and then proceed to the qualitative mapping phase, whose global results are shown in Table 2.

Table 2
Grade/Category distribution results for the 2008-09 and 2009-10 LEI Graduates

Grade	Competence	Skills	Knowledge
A – Excellent	11%	11%	5%
B – Very Good	54%	25%	25%
C – Good	25%	59%	54%
D – Sufficient	10%	5%	16%

4. For each graduate in the sample its corresponding qualitative proficiency level in the Knowledge, Skills and Competence categories was determined and a global list produced for further analysis and review.
5. After some threshold tuning the final grading list was produced, from which Figure 8 was derived.

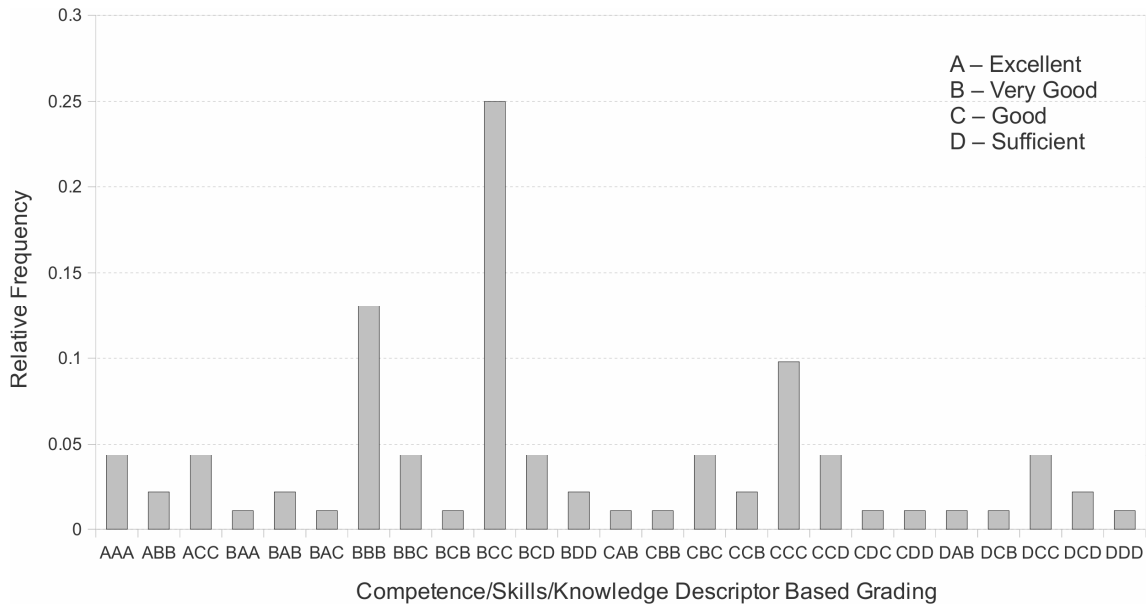


Figure 8. Descriptor based grading for 2008-09 and 2009-10 LEI Graduates

Analysing Figure 8, in which each three letter group represents (from left to right) the grading in Competence/Skills/Knowledge, we find 25 of the 64 possible grading combinations with the following grading peaks (stereotypes):

- BCC: very good in Competence, good in Skills, good in Knowledge;
- BBB: very good in Competence, very good in Skills, very good in Knowledge;
- CCC: good in Competence, good in Skills, good in Knowledge.

It is also worth mentioning that 11% of LEI graduates have “excellent competence”, but on the counterpart 16% only have “sufficient knowledge”.

CONCLUSIONS

This paper is a first attempt to grade not only knowledge and expertise acquired and practiced during engineering education, but also personal, vocational and societal aspects mainly related to skills and competence. The proposed descriptor based grading system aims to address and answer important issues known for many years (at least in Portugal):

- The “knowledge” oriented cumulative grading point average method, typically used to rank engineering graduates, is too much simplistic and even misleading, because it ignores that engineering is much more than “knowing things”;
- An engineering graduate has many non-knowledge related facets and some of them are very important for employers and other societal agents, but information about those facets is not officially available or endorsed by HEIs;
- Most employers disregard the “program grade” as an indicator of engineering quality, because it amalgamates things which are not comparable, and look for extra information about the graduates by email, phone, etc;
- The Capstone Project is prone to environmental factors that can affect the course grade. As such, it is not suitable to qualitatively describe all aspects of engineering proficiency.

The proposed descriptor based grading system may be seen as a natural consequence of CDIO adoption and its extensive use at the LEI Program in ISEP, but it needs to be verified and validated by external stakeholders and employers, looking for potential improvements. If

this descriptor based grading approach is found useful, we foresee that the grading classification may be included in the Diploma Supplement [8].

Despite its flexibility, the proposed grading system must be used with care, especially by employers. If an employer knows what it is looking for, a system like the proposed one may be very useful. Let us consider three examples of employer needs in terms of Figure 8:

- Graduate with a “scientific emphasis”: look for profiles like **A or **B (e.g. DAB).
- Graduate with a “customer contact emphasis”: look for profiles like *A* or *B* (e.g. CAB).
- Graduate with a “development emphasis”: look for profiles like A** or B** (e.g. ACC).

The proposed grading system has been able to identify a few relevant “graduate stereotypes” (Figure 8) which seem to be in good accordance with the personal experience of ISEP and LEI managers. Having such a small set of significant graduate stereotypes, if confirmed by external stakeholders and organizational leaders, may be used to fine tune the LEI Program and increase its “productivity”.

Finally, although it is possible to develop a more complex and granular system, we think that too much complexity and information may lead to a less useful grading system, in which high level trends and “phenomena” may be difficult to identify...

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Biographical Information

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INDUCTIVE TEACHING BY INTERACTING WITH CDIO-PROJECTS

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ABSTRACT

The paper describes experience with the use of CDIO-project results in a traditional course, taught for both those students who will attend the relevant CDIO-project and those who will not. The classic course in concrete structures interact with the CDIO-project, both by using project results as a inductive starting point for the traditional teaching and by creating a basis for a CDIO-project, which runs parallel to the last part of the course. The use of such results as a starting point for the teaching allows the teacher to start with simple observations from tests and to build the general understanding of the assumptions and formulas on such observations, thus linking objective, simple observations to the classic theories. The use of the results improves both the students understanding and motivation and illustrates the clear link between the reality and the theories and formulas. This has also the added benefit that it proves to the students that their project results are valuable and useful, which again increases motivation in the course and in the projects.

KEYWORDS

Inductive teaching, experiments, videos, students own contributions.

INTRODUCTION

Teaching engineering students involves a number of activities: We have to teach them both the basic technical design rules and theories and teach them to think as engineers and scientists. This is quite a challenge and we constantly try to update, improve and adjust our teaching to reach these goals as well and as efficient as possible.

An investigation [1] of the candidate's competences was recently carried out by questionnaire; send to over 300 of the newly graduated candidates (1-5 years experience) from the Department of Civil Engineering (BYG) at the Technical University of Denmark (DTU) and over 300 of their employers. This investigation did also ask which competences should have the highest priority and revealed that both the students and their employers report that the

1. Engineering thinking;
2. Basic engineering knowledge;
3. Personal skills;
4. Communication skills;

are the most important competences for an engineer. This fits quite well with the points identified by MIT [2] in connection with the development of the CDIO concept.

DTU provides a very good basis for the basic knowledge and the specializations as DTU offers a large number of courses and more or less predefined projects (totalling 1175 [3]) in addition to the bachelor and master projects. These courses are divided into basic BEng-courses (225 courses, all in Danish), basic BSc-courses (125 courses, all in Danish) and advanced courses for the MSc and PhD-students (775 courses, all in English) in order to provide both basic and advanced courses and projects.

A large part of these courses are, however, traditional deductive courses and may not train the engineering thinking as efficient as possible. The introduction or strengthening of CDIO-activities combined with a more inductive approach should have a very good chance of improving the student's ability to think as engineers.

A problem observed [4] is that the students find it difficult to have an overview of how the content of a specific course relates to the rest of their study and their later work as engineers. The students reach the overview towards the end of their bachelor study, but it would be an improvement if the student could get such an overview earlier and easier.

Students and teachers agree that the student's motivation and understanding increases significantly, when the use and relevance of the session and the course is easily realised by the students. BYG aims therefore at linking the classic theories in the sessions and courses to real structures, observations or experiments, in order to facilitate the overview, to encourage the students to use their logical sense and (of course) to improve the students motivation.

The use of CDIO projects and use of inductive teaching are main parts of this strategy, as this paper will illustrate with the inductive use of CDIO-project results in teaching of classic courses in basic concrete structures.

THE STUDENTS AND THE TEACHERS

BYG offers a total of 140 courses annually, taught either once or twice a year, in order to support our 9 different building engineering educations. It is therefore necessary to describe the bachelor student population and also the teacher team for the teaching of concrete structures.

Our many different students

BYG is responsible for the teaching 5 building engineer educations on the bachelor level and 4 educations at the master level (www.dtu.dk). The bachelor educations include:

1. BEng-students in the field of Building Engineering, starting in the spring;
2. BEng-students in the field of Building Engineering, starting in the autumn;
3. BEng-students in Arctic Engineering, starting in the autumn;
4. BEng-students in Architectural Engineering, starting in the autumn;
5. BSc-students in Civil Engineering, starting in the autumn.

The BEng-students have fixed combinations of courses during their first four semesters, after which they have a mandatory semester in a company. The Building Engineering students will often work on constructions sites, either as contractors or consultants, whereas the Architectural Engineering students tend to work for the design companies, architects or consultants. The students have then two additional semesters at DTU to finalize their education.

The Arctic Engineer students follow courses on Greenland for the first four semesters, where teachers from BYG in Lyngby are flown in to teach for shorter, intense periods in cooperation

with BYG's permanent staff at Greenland. These students have an additional four semesters at DTU in Lyngby with a mandatory semester in a company and graduates as Building Engineers with the additional skills and focuses, required for the Arctic Engineering.

The BSc-students in Civil Engineering follows a more flexible list of courses and are required to study six semesters in order to reach the bachelor degree.

All these educations require a total of 180 ECTS-point and will differ from each other, both in the list of courses and in their focus.

However, certain technical areas are taught to all at approximately the same stage in their education and this means that all are taught basic concrete structures in the courses 11311 (BSc), 11746 (BEng-Building and Arctic) and 11941 (BEng-AE) [3] in the spring semester, normally corresponding to their fourth semester, but in some cases in their third semester – but always prior to the BEng students mandatory fifth semester in a company.

Our concrete structures teaching team

The teaching of the three basic concrete structures has jointly been carried out by a group of teachers, who have also been involved in the CDIO-projects to some extent:

- A. An older, very experienced professor, (over 30 years at DTU).
- B. A newer professor, educated in Germany and USA, (over 5 years at DTU).
- C. A newer professor (the author), educated in Denmark, (over 5 years at DTU).

The number of different educations makes it a challenge to teach the students efficiently, but it provides a very good opportunity to test new teaching approaches on different groups of students. The teachers A and B have used the traditional, deductive approach, whereas teacher C (the author) has moved towards a more inductive based teaching approach, using contributions from the student CDIO-projects or other student projects.

INDUCTIVE TEACHING OF STUDENTS

The author has introduced systematic use of samples, test specimens, photographs and videos in the teaching of concrete structures. The intention was to illustrate the use and the relevance of the topics taught to the future work as an engineer and to strengthen the link between the theories being taught and reality (as observed in tests or even better in collapses of actual structures) and to increase the student motivation, as an increased motivation leads to better learning.

This has later been improved so lectures are initiated by a small demonstration, by tests or by videos showing e.g. the failure mode, dealt with in the lecture, as this has been found to provide a good basis for the understanding of assumptions and estimations. The material used was at first been supplied by the industry, but has more recently been obtained from student's or past student's lab exercises, CDIO-projects and later bachelor or master projects.

The use of the material in the inductive teaching can best be illustrated through the steps in Kolb's classic learning circle [5], as this will be a simple way of illustrate the thinking and the students involvement.

Kolb's learning circle

The results from the CDIO-project 11702 Beam Testing, where the students cast and test concrete beams are used for the session on deflections and cracking and also for the

session on bending moment capacity. The use of this follows Kolb's well-known learning circle [5] of why, what, how and what-if through the lecture and the exercises.



Figure 1. Test set-up for the concrete beam with student marking the cracks (traditional)

Step 1: Why

Teaching engineering students usually includes teaching the students to evaluate and estimate the structures performance, as e.g. deflections and load-carrying capacities. In the field of concrete structures, we do of course have design rules and theories and formulas for estimations and these have always been verified by substantial amounts of testing, (just as student projects often carry out testing as documentation in their projects).



Figure 2. Extract from video available at YouTube [6], showing beam behaviour at failure.

The students tested beams and produced a video recording of the test. The video has been stored at YouTube [6] and allows the actual bending failure to be observed, just as frames may be extracted from the original video and shown in Figure 2. Several of the tested beams are also kept available for inspections and discussions in the auditorium.

The video shows that such a failure mechanism needs to be considered (just as other videos show why those other failures need to be considered as well).

Step 2: What

The video shows clearly what is happening in the failure mechanism. It illustrates the plastic behaviour of the reinforcement (yielding is required to create the large cracks); just as it shows the plastic failure of the concrete in the compression zone and in which areas and directions you may utilize the strengths of the concrete and the reinforcement.

The video and the beams illustrate in a very simple manner a number of the assumptions for the classic theories and encourage the students to form an opinion, based on their own observations (and it is the author's impression that this approach makes the theory a lot simpler to understand, than the classic deductive approach).

Step 3: How

Based on the video, the test beams present in the auditorium and the screen capture in Figure 2, it is possible to make a simple engineering estimate of the capacity by analyzing the failure mode as shown in Figure 3. The formulas derived in this manner are identical to those used for normal concrete, although modifications are required for more special concrete types.

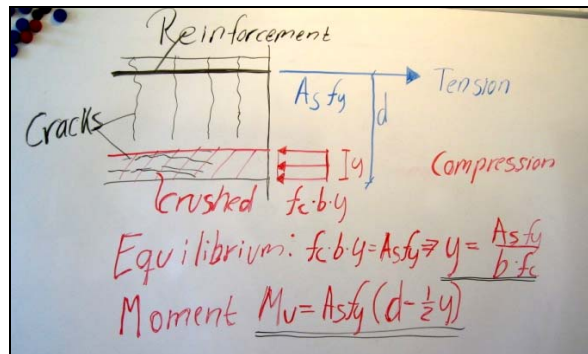


Figure 3. Analysis of failure mechanism.

Additional test data available may be used for estimating the capacity of this beam and provides a good opportunity to stress the fact, that there are variations in geometry, material strengths and beam capacities – even for identical concrete mixes and identical beam geometries (with so many students doing CDIO-tests, you will have variations – just as you have it on the construction site).

Step 4: What if ?

The session on bending moment capacity has until this point dealt with the observation and analysis of the observed failure in that actual beam (autopsy style). We proceed after this to establish the limitations to the model based on theory already known by the students and our autopsy of the beam.

We work at this stage already on the what-if angle: What if we change the strengths, the geometries etc. and we generalize the simple estimations to the theories required to cover all the bending designs.

It needs also to be said that the lecture is followed by theoretical exercises in the same four hour session, where the students estimate beam capacities, check conditions etc. The courses are normally followed by project work outside these courses, which either run in parallel with the courses or in the following semester.

Student response

All courses and involved teachers at DTU are evaluated in questionnaires by the students towards the end of the course, just as the students may comment on the course, the teaching and the teacher. The evaluation of the teacher includes three important statements:

1. I think that the teaching gives me a good grasp of the content of the course;
2. I think the teacher is good at communicating the subject;
3. I think the teacher motivates us to actively follow the class;

to which the students can choose one of five answers: 1) Agree totally; 2) Agree; 3) Neutral; 4) Disagree; or 5) Disagree totally.

We can compare the classic deductive approach to the inductive approach through the standard evaluation [7] of the teachers (Deductive = teacher 1+2, Inductive = teacher 3), in order to evaluate the differences in student's motivation, the students understanding of the topics and their motivation.

Table 1
Student response to statement: "I think that the teaching gives me a good grasp of the content of the course"

Group	BSc-CE		BEng-B		BEng-AE		All	
	I	D	I	D	I	D	I	D
Approach								
Agree totally	34%	11%	56%	25%	45%	10%	47%	18%
Agree	44%	39%	35%	38%	45%	30%	39%	38%
Neutral	17%	34%	7%	22%	5%	20%	11%	26%
Disagree	3%	13%	1%	5%	0%	35%	2%	11%
Disagree strongly	2%	3%	0%	9%	5%	5%	1%	6%

Table 2
Student response to statement: "I think the teacher is good at communicating the subject"

Group	BSc-CE		BEng-B		BEng-AE		All	
	I	D	I	D	I	D	I	D
Approach								
Agree totally	46%	11%	67%	25%	75%	5%	60%	18%
Agree	37%	33%	23%	41%	20%	14%	28%	35%
Neutral	14%	34%	9%	16%	0%	43%	10%	26%
Disagree	2%	17%	1%	7%	0%	19%	1%	12%
Disagree strongly	2%	5%	0%	11%	5%	19%	1%	10%

Table 3
Student response to statement: "I think the teacher motivates us to actively follow the class"

Group	BSc-CE		BEng-B		BEng-AE		All	
	I	D	I	D	I	D	I	D
Approach								
Agree totally	42%	9%	64%	20%	55%	10%	55%	15%
Agree	41%	23%	24%	41%	40%	14%	32%	31%
Neutral	14%	50%	10%	20%	0%	38%	10%	33%
Disagree	3%	14%	2%	11%	0%	33%	2%	15%
Disagree strongly	0%	3%	0%	9%	5%	5%	1%	6%

The Tables 1 to 3 presents the answers from app. 200 students from the three main groups of students (BEng Arctic listed under BEng-B), just as the Figures 4 to 6 present the average of all the students' responses.

It is clear from this that the students appreciates the more inductive approach, that it gives them a better grasp of the course content, makes it easier to understand the teacher and that this approach motivates the students to active follow the class.

One of the most interesting observations here is probably that the inductive approach with a combination of observations and theory is a success with all the different types of students: This indicates that it should be implemented in a larger number of courses.

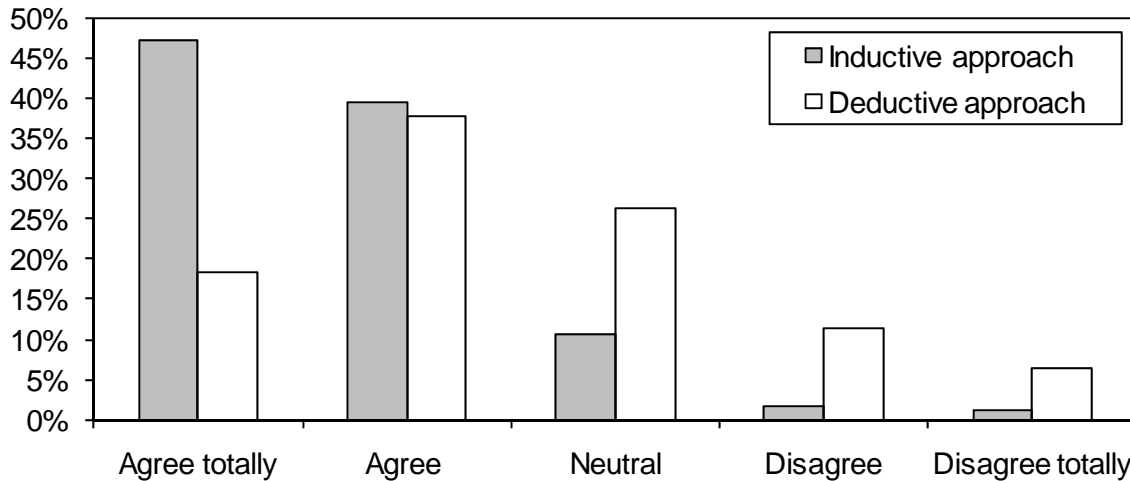


Figure 4. Student response to statement: "I think that the teaching gives me a good grasp of the content of the course" – all groups

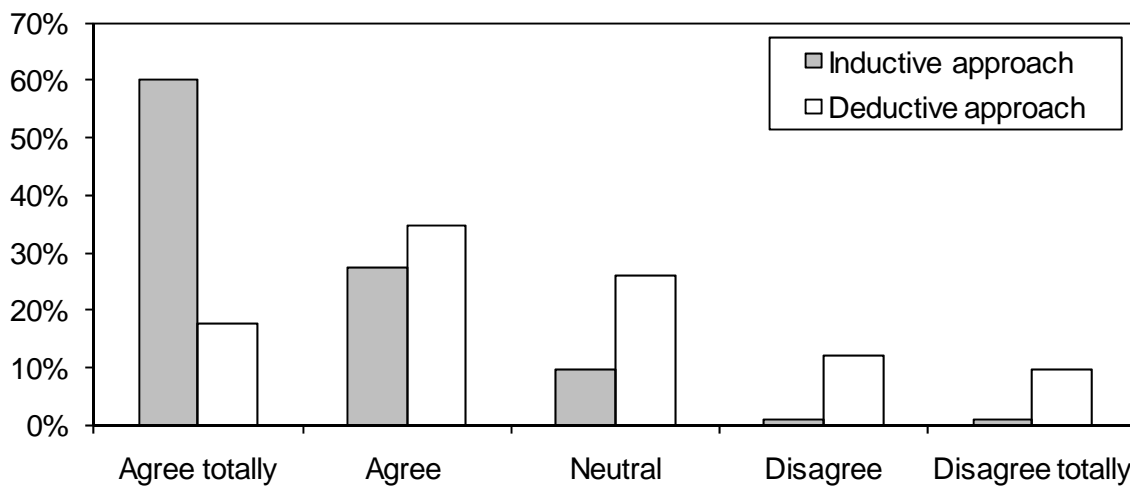


Figure 5. Student response to statement: "I think the teacher is good at communicating the subject" – all groups

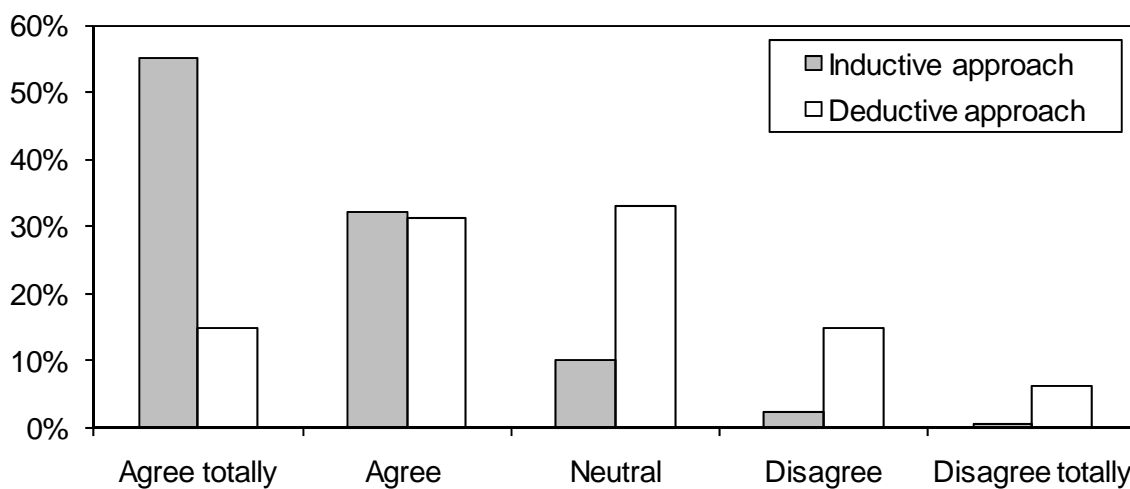


Figure 6. Student response to statement: "I think the teacher motivates us to actively follow the class" – all groups

INTERACTION BETWEEN COURSES AND CDIO-PROJECTS

The semesters at DTU are divided into 13 weeks of teaching in a number of courses, followed by examinations over a few weeks and followed by a 3 week period, where the students work with one project or one course full time.

The basic concrete courses are taught in the 13 week period in the spring and will be combined with the CDIO-projects in different ways for the different student groups

1. BEng-students in Building Engineering, starting in the spring: This group will have a CDIO-project 11702 dealing with casting, testing and analyzing concrete beams during the last half part of the 13 weeks period at their semester. The concrete course teaches beam theory and design during the first half part of the same 13 week period. The students will follow 11742 in the following semester and have their semester in practice in the fifth semester.
2. BEng-students in Building Engineering, starting in the autumn: This group has a large CDIO-project 11742 Design of Structures in the 13 week period, parallel to the concrete structures course (but it may be changes so that project runs over both the 13 weeks and the 3 weeks period, as this would enable a better project). These students will have their semester in practice in the following semester.
3. BEng-students in Arctic Engineering, starting in the autumn: These students are few up to now and attend the teaching at DTU (courses and projects) as a part of either group 1 or 2 above.
4. BEng-students in Architectural Engineering, starting in the autumn: These students have a CDIO-project 11945 on Sustainable Design during the 13 week and 3 week period in which they to some extend use the results of the concrete structures course, but with a strong focus on energy. DTU is, however, strengthening the focus on sustainability in all courses, including the concrete structures courses and an improved interaction is expected.
5. BSc-student in Civil Engineering, starting in the autumn: These students have a CDIO-like project 11691 on Integrated Design, including an initial design of the concrete structures. This project runs during the 13 week and 3 week period.

It need to be stressed, that on top of all the CDIO-projects, all students at the BYG are offered a material technology course with testing of materials, including traditional testing of reinforcement bars and concrete cylinders, just as bachelor students are offered experimental work each semester.

These interactions are not always easy to arrange, however, cooperation between the many CDIO-projects and the classic courses is a benefit to all. The reported experiences show that both types of teaching can be improved by cooperation, where the courses support the CDIO-projects and these projects in return use the content taught in the courses as well as produce additional teaching material for the courses.

CONCLUSIONS

It can be concluded that the introduction of inductive elements in the classic courses in concrete structures is a clear success, both in aspects of student motivations and in the actual understanding of the topics.

It is also the author's impression that use of the students – or other students – own results, samples, videos etc. is much more convincing and motivating than use of more professional videos and tests, produced by professors and professional photographers. This type of teaching material obtained from students seems actually to appear more genuine and

convincing and it proves to the students, that their work is appreciated and used, which again improves the students motivation.

Using results from CDIO-projects in the supporting courses is also an efficient way of creating cooperation between the CDIO-project and the traditional courses: cooperation is after all a situation, where both parties benefit. This will both create a better cooperation among teachers and enable the traditional courses renewal through a steady flow of additional teaching material, created as one of the results of the CDIO-project.

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Bibliographical Information

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An introductory course for software engineers

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ABSTRACT

The aim of this paper is to show one example of how an introductory course for software engineers could be organised. Our course introduces the students to the main ideas of CDIO, allows them to practise conceive, design, implement and operate in a complex team based environment while developing basic communications skills. Furthermore, the students are introduced to ethical issues concerning working as a software engineer and will meet with professionals and learn what generic skills industry expect from students. The course is popular with the students and has made them understand the need of incorporating the practise of generic skills with the learning of technical and scientific knowledge.

KEYWORDS

Introductory course, software engineering, ethical issues, professional skills.

BACKGROUND

In a study program adapted to the ideas of the CDIO initiative it is essential to introduce a framework for engineering practice early in the education. The importance of this simple fact is captured in standard 4 of the CDIO. When developing the introductory course at our department we wanted a course in software engineering that would enable the students to

- understand the concepts of CDIO and how it is incorporated in their study program,
- practise conceiving, designing, implementing and operating in a team based environment,
- learn the basics in oral and written communication and working within a team,
- reflect on the ethical issues of being a software engineer,
- understand their future profession and start the process of being able to set goals for their future career.

This paper describes the introductory course and some design choices we made in the development of the course to meet the defined needs.

The outline of this paper is as follows; first, the underlying design choices of the course are described. Second is it shown how we put CDIO into a software engineering context. Third, the generic skills trained during the course are described. Finally, some quantitative and qualitative results of the course development are given.

THE MAIN IDEA OF THE COURSE

During the development of the course we used constructive alignment [1] to make sure the students would be able to reach the set learning outcomes of the course. The constructive alignment of the course are summarised in Table 1.

In order to practise conceiving, designing, implementing and operating in a team based environment the course was chosen to be project based to a large extent. The class was divided by the teachers into teams of five students and the task of the project was to implement a game suitable to twelve-year-old girls to be launched at a specified website. The website (kpwebben.se – in Swedish only) has a relatively strong ethical integrity and the game should be adapted to this. The teams should use the tool GameMaker (www.yoyogames.com) to do the implementation.

The project-aim was carefully selected. The challenge to construct a game made the task fun and interesting. It was also possible to use a powerful tool that required absolutely no prior knowledge in programming. All implementation work in GameMaker can be done without any code-writing. The reason for this was that we wanted to give everyone in a project group a chance to contribute to the project, not only those who had previous experience of software development. The target group of the game, twelve-year-old girls, made sure the students had to work carefully during the conceive and design phases of the project. The students (typically nineteen-year-old males) could not solve the task by introspection; they had to look outside themselves to figure out what twelve-year-old girls want from a game and then be able to construct such a game. The purpose of setting the target group of the game to girls was to naturally initiate discussions on whether there were differences in game preferences between boys and girls. The purpose of the ethical integrity of the proposed website was to make it possible to initiate discussions on ethical issues. Discussions on the ethical aspects of being a professional engineer were also initiated in the context of working together in a group.

The work with the project was divided into four different parts, where each part was devoted to each one of the steps in C-D-I-O. It was, however, made clear to the students that even if working with the project followed a rather strict waterfall model [2] this is not the case in real software engineering projects. We clearly pointed out that the simplistic waterfall model was for educational purposes and that they later on in their education would learn more realistic and agile project models.

The two study programs that have the course in their syllabuses are the five year master's program in computing science engineering and the three year bachelor's program in computing science. Since one aim of the course is to introduce the study program to the students, the program directors of the two study programs were responsible teachers on the course.

LEARNING HOW TO CONCEIVE, DESIGN, IMPLEMENT AND OPERATE IN A SOFTWARE ENGINEERING CONTEXT

At the very first lecture of the course, a discussion regarding different ways of organising a study program was initiated. In a teacher led discussion the students were made to see the benefits of having a strong context for learning and letting this context be an active part of the study program. It was explained why CDIO is a valid context and some examples of how CDIO influence the study program were given.

Each of the four C-D-I-O-parts of the course lasted approximately one week and the students devoted about 50% of their time to this introductory course. The other 50% were devoted to

an introductory course in mathematics. Each of the four parts of the course started with a lecture where the current concept was explained and exemplified in a software engineering context, as is described below.

Conceive – Problem solving basics, project plans, setting system goals, forms for working together, performing basic investigations,

Design – The design process, an in-class workshop on creative processes', brain storming, scenarios, personas,

Implement – Building the correct thing vs. building the thing correctly, testing, an introduction to extreme programming, pair-programming, time-boxing, the pomodoro method,

Operate – The importance of maintenance, tips on writing manuals, organising support, handling software errors, different types of software errors.

The different phases of the project work were assessed in the following way:

Conceive – At a cross-team seminar the conceive phase was discussed and special focus was put on the teams' findings on what a twelve-year-old girl would demand from a computer game in order for it to be "interesting". Some focus was also put on the implementation tool, what could and could not be easily done with the tool. The seminar was monitored by a teacher and at the seminar some teams were recommended to improve their research on the expectations of twelve-year-olds. The teacher also made sure that all students participated in the discussion and checked that all students were well prepared.

Design – At a cross-team poster session the game design was presented. Each member of the team had to orally present the poster to the cross-team during five minutes. During the following five minutes the cross-team asked questions and came up with suggestions of improvements. After the session the team had to collect all comments that the team members had received during the cross-team session. In this way the team received feedback from four different cross-teams. The posters were also assessed by the teachers and feedback on the poster design was given at tutoring sessions. The tutoring sessions are further described in the Learning Generic Skills-section.

Implement – The implementation was presented at an oral presentation where each team was given 20 minutes to present their implementation of the game and to justify design choices etc. The presentation was to be aimed at a teacher of the course. The audience (i.e. other teams) gave feedback to the team's presentation. Each member of the team had to have an equal amount of "floor time" during the presentation and everyone received individual feedback on their performance in the presentation from a teacher afterwards.

Operate – A group of twelve-year-old girls and a member of staff evaluated the games. The girls focused on the gaming experience and graded the games on a variety of different topics. The member of staff focused on the potential of the game concept. At a public presentation each team was given five minutes to pitch their game to a general audience and the pitch was assessed by a member of the staff.

LEARNING GENERIC SKILLS

In addition to the CDIO-lectures, there were also lectures on topics like oral communication, group processes, written communication, professional ethics and setting personal goals. Materials regarding scientific writing, oral presentation and how to make a poster was available online.

Every week each group of students was tutored by the program directors. During these sessions one particular topic was discussed and the previous week of the course was evaluated. Examples of topics discussed were: the anxiety of oral presentations, how to study efficiently, problems involved in writing reports etc.

In addition to the project work the students were also assigned the task of writing an individual report on their professional role as software engineers, focusing on the ethical aspects and the generic skills that would be expected from them as professionals. To aid the students in their work, twelve companies were invited to present themselves and participate in a panel discussion. The companies were asked to focus on technical aspects of their work in their presentation and were informed that the students would be interested in knowing more about generic skills and ethical aspects during the panel discussion. During the afternoon there were several occasions when students and professionals could mingle. Several companies were represented by more than one person so the student to professional ratio was about four to one, making mingling meaningful.

The individual report should also contain an analysis of correlations between the observations drawn from interacting with the professional software engineers, the CDIO-syllabus [3], the syllabus of the study program and the ACM Code of Ethics for software engineers [4]. The purpose of writing this analysis was to make the student reflect on

- whether the study program was aligned with the formal documents of CDIO and ACM
- whether the syllabus's of CDIO and ACM was aligned with the needs of the industry
- and finally whether the study program would help the students reach their goals of being efficient software engineers after graduation.

RESULTS

At the student appraisal for 2010 the students gave the course a 4.3 grade on a 5 grade scale. The students were particularly pleased with the lectures, the project and meeting the professionals. Some of the students felt that the report on their future professional role was unnecessary.

The course was similarly organised in 2009 and besides being popular with the students we have noticed a larger acceptance amongst the students for including the practise of generic skills in other courses. In addition to this, a course in interaction design, which previously was considered "fuzzy", largely due to the fact that it contained no programming, has gained in popularity amongst the students after the introduction of the new introductory course.

The introductory course has also been accompanied by a short term-introduction for each year at the very beginning of each term. At these introductions the program director meets with the entire class over an informal lunch. Each course in the upcoming term is introduced and its role in the program is explained and discussed with the students. In addition to this the past term is followed up based on an informal discussion taking its origin in the students' appraisals of the courses last term. The students find these term-introductions very valuable.

The idea of using a website with strong ethical standards did not work as well as intended. The reason is simply because the students soon understood that their games were not really to be launched at the website this requirement did not become as steering as we intended. Still we believe that all games developed would have met the ethical requirements of the website. To use twelve-year-old girls as target group was very successful. At first it was clear that the students projected their own values on how a good game should be and these

values was, in some cases, definitely not what the target group wanted. One example was high-score lists. For nineteen-year-old men high score lists, preferably lists available on-line, seems to be essential of the gaming experience. For twelve-year-old girls it is not. In fact, the girls did not seem to be that interested in scores at all.

The games constructed by the students can be found at <http://www8.cs.umu.se/kurser/5DV107/HT10/spel/>
Instructions are mostly in Swedish.

Table 1 Constructive alignment of the course

<i>Learning objective</i>	<i>Assessment</i>	<i>Teaching</i>
Be able to understand and perform the conceive phase of a project	Seminar	Lectures, tutoring
Be able to understand and perform the design phase of a project	Poster session	Lectures, tutoring
Be able to understand and perform the implementation phase of a project	Oral presentation of project	Lectures, tutoring
Be able to understand and perform the operate phase of a project	Oral presentation of product, target group evaluation	Lectures, tutoring
Working together in a group	Project	Lectures, workshop, tutoring
Understand the skills needed for a professional software engineer	Report	Lectures, workshop, meeting with professionals
Insight into the ethics of being a professional	Report	Lectures, meeting with professionals
Oral communication	Discussion seminar, oral presentation	Lecture, tutoring
Written communication	Report, poster	Lecture, tutoring

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Biographical Information

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TAKING THE CLASSICAL LARGE AUDIENCE LECTURE ONLINE USING TABLET COMPUTER AND WEB CONFERENCING FACILITIES

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ABSTRACT

During four offerings (September 2008 – May 2011) of the course 02402 Introduction to Statistics for Engineering students at DTU, with an average of 256 students, the lecturing was carried out 100% through a tablet computer combined with the web conferencing facility Adobe Connect (version 7). This enables some extended possibilities as compared to the standard large audience university lecture:

1. Recording and subsequent online sharing of the entire lecture activity
2. Simultaneous (synchronous) viewing of the lecture on different locations (including smart phone based viewing)
3. Active student participation through chats and polls.

In this paper it will be described exactly how this can be done using audio and video equipment. The experience from different technical solutions will be described. A quantitative and qualitative analysis of the course evaluations are given that documents that students reacted positive to the initiative. The one year hit statistics of almost 10.000 during 2010 on the resulting output lecture videos indicates that the approach has a clear impact.

KEYWORDS

Technology-enhanced learning, web conferencing, video recording, tablet computer, large audience lecturing, teaching statistics.

BACKGROUND AND METHODS

The direct occasion for initiating this approach to the lecturing in the course 02402 was a sudden increase in the number of students signed up for the course in August 2008: At course start the number was more than 380 students. It was decided to simultaneously transmit the lecture in one (large) lecture hall to a neighbouring lecture hall. At that point in time the recording option of the Adobe Connect meeting room facility was just an added premium and the interactivity potentials of the meeting room was not used nor explored. A digital camcorder was operated by an assistant during the lecture. The video was primarily used to show/provide a small video pod of the lecturer in the corner of the meeting room screen transmitted and recorded, cf. Figure 1. The audio was taken from the inbuilt lecture

hall Sennheiser audio equipment using a headworn microphone. It is an Adobe Connect built in feature that a pod showing the video and providing the audio can be included.

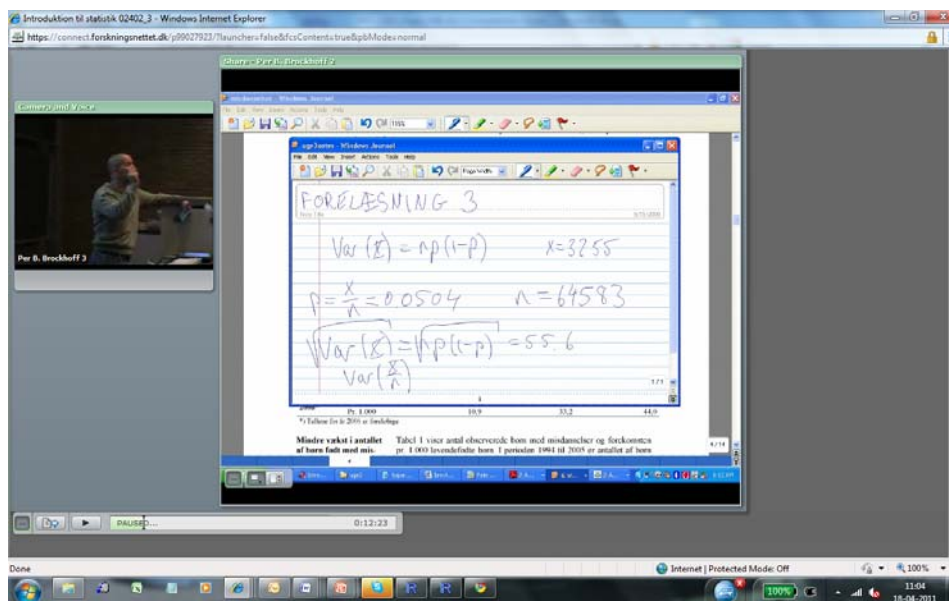


Figure 1

Example of the form of a recorded lecture (02402 lecture 3, 16/9 2008). This is how a recorded lecture appears when subsequently viewed through a web browser. (In this case on a windows based laptop using Windows Internet Explorer).

A key point in making this a workable approach is the fact that a tablet computer is used. In Adobe Connect the computer desktop can be shared in the main pod window, see Figure 1 and 2. This means that all the lecturing teaching instruments can be incorporated into the tablet computer and shared with everyone, including the following instruments used in the 02402 course before the Fall 2008 version:

1. Computer presentations (pdf and/or Powerpoint)
2. Example material on overhead slides – including potential hand writing on slides
3. Internet information using browser
4. Statistical software examples and tutorials
5. Key text book (statistical) tables and figures copied on overhead slides
6. Blackboard based review of key technical issues and example material

Point 1, 3 and 4 are straightforward. Point 5 is handled by scanning-and-viewing instead of using the overhead projector slides. And 2 is handled by viewing the example material on the computer screen instead. And since the tablet computer, in this case a Windows operated one, comes with a hand writing/annotation feature, Windows Journal, that allows you to hand write on any kind of file by printing/inserting it into Windows Journal. Even certain features within Adobe's pdf-viewing and Powerpoint presentations allow for direct hand writing/annotation. Point 6 is handled in the same way, see Figure1 for an example of using the "Blackboard on the Computer" by Windows Journal. A benefit of all this is the ability to easily share these hand written supplements by creating subsequent pdf-handouts of everything.

An important issue after the first round in 2008 was to be able to do the recording in a technical easy-to-use ("plug-and-play") way. In later versions the assistant operated camera was substituted by a fixed webcam with an extension cord and various solutions for the audio capture was tried. The interactive simultaneous student participation was initiated during the 3rd offering. An overview of the different approaches used is:

- Autumn 2008: (350 participants)
Real video camera using video recording assistant, simultaneous transmission to other auditorium. Subsequent upload.
- Spring 2010: (184 participants)
Use of webcam, subsequent upload – sometimes ONLY the audio. In addition English lectures made with webcam without audience.
- Autumn 2010: (310 participants)
Use of webcam, subsequent upload. Half of the period: Also simultaneous participation in meeting facility (simultaneous watching via internet possible)
- Spring 2010: (174 participants)
Use of webcam, subsequent upload AND simultaneous participation in meeting facility (simultaneous watching via internet possible).

The conclusion so far is that a fixed webcam can do a sufficient job, since the video of the lecturer plays no major role in the final lecture videos. The webcam can be positioned such that it captures a few meters of the key “lecturing scene” meaning that the lecturer will be in the picture most of the time, but should he/she step out of the picture every now and then, it is not critical for the end result. Of utmost importance is the audio quality and combined with the wish to be cordless it puts some challenge to the technical equipment, if the best audio result is sought. During the numerous recordings carried out in these four course offerings (and other courses) a number of different simple and cheap audio solutions were tried. A Bluetooth based solution seemed nice, but turned out to be too unstable. If you (in some situations) can cope with not being cordless, a simple corded headset seems to provide a feasible solution. More generally, to obtain easy “plug-and-play” high quality cordless audio, the conclusion is that a portable version of some professional audio system, e.g. Sennheiser or Mipro, combined with a headworn microphone and bodypack is expected to provide the best and most stable result. And still this equipment is small enough to be easily carried around.

Inviting students to actively participate in the meeting room during lecturing

As listed and mentioned above, the latest feature initiated is to invite students to actively participate in the meeting room during the lecturing – whether they are located in the lecture hall or not. This was initiated during the 3rd offering in the Fall 2010, and from the beginning of the Spring 2011 offering. Since chat pods and poll pods are readily available in Adobe Connect, it was straightforward to setup the meeting room to include those facilities. In Figure 2 an example of how it could appear is shown. One chat pod and three poll pods are used here. So far, the chat pod is aimed at having the students asking “follow-up” questions, that is, pointing at things they would like to have clarified by the lecturer in a sub-sequent lecture/video clip. One of the poll pods are used for voting for such potential requests. In the example given here, two more polls are given: One just for fun: asking about the general mood of students today. The other is used for collecting data used as example data in the actual statistics lecturing. In this case the weight of each individual is asked for. Then during the break of the lecture, these data is transformed to the statistical software of the course and subsequently used in the last part of the lecture.

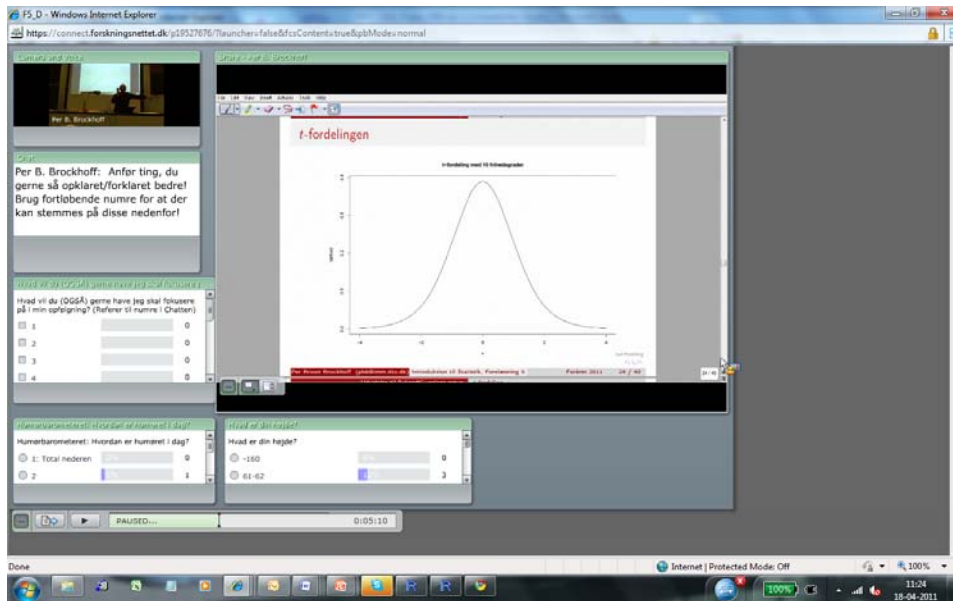


Figure 2

Example of the form of a recorded lecture using chat (one pod) and poll pods (three) (02402 lecture 5, 1/3 2011).

Students participated through their own laptops or by iPhone. At the time of doing this the only smart phone option with the available version 7 Adobe Connect was provided by an iPhone App that only supported parts of the meeting room activity, e.g. the poll feature were not supported. This is something that is changing these months: with the Adobe Connect version 8 and updated Apps for as well iPhone as Android phones increased options for smart phone based participation will develop. In the first try during the 3rd course offering only very few students decided to participate. A practical challenge was that since the primary access approach would be by laptop, the lecture hall should be able to provide power plugs for the individual student to expect them to power on their laptops. This was not available in the 3rd course offering. In the 4th offering (Spring 2011) this was available and the concept was introduced to the students from the beginning of the course. The current activity level amounts to having around 20-30 students as active participants in the meeting during the lectures - most of these sitting in the lecture hall using their own laptops, but also some from other locations. Among the 174 registered students, roughly 50% is appearing in person at the individual lecture. In [1] a short demonstration of how the teaching in this way is carried out in practice.

OUTPUT

As a side effect of this way of teaching, complete collections of video lectures can be collected and shared without any specific connection with running courses. A note to make here is that it is an inbuilt feature of the Adobe Connect that the recordings can be easily shared simply by sharing an URL – no handling of video files is needed by the user. In writing, close to 200 of such recordings of lectures by the author have been shared with at least the course participants. More recently, public sharing of various videos became more focussed through three open web-sites, cf. [2], [3] and [4], that collects the following:

1. Introductory statistics lectures in English (642 visits during Feb-March 2011)
2. Introductory statistics lectures in Danish (455 visits during Feb-March 2011)
3. More advanced statistical lectures (very recently published)

The English introductory lectures are the only lectures not recorded in a lecture room with audience. The current language situation for the introductory course is that it is (and must be) given in Danish – although using an English textbook. But then the course is given in English in parallel for a relatively small number of participants – around 20 in each course offering - and using the recorded video lectures as a (cheap) way of making this happen. During the Spring 2010 offering the English lectures were created and used during the course in the following way: The non-Danish speaking students were promised that the recorded lectures would be available no later than at the starting time of the Danish lecture each week. And then they were invited to participate in the same post-lecture exercise activity as the Danish students. The lectures were then recorded at the office of the lecturer.

There has been a development of the length of the individual recordings over the four course offerings: In the first one the entire 2x45 minutes lecture and the break(s) were recorded in a single video. In the English versions they are more focussed and with no breaks but still only a single video for each of the 13 (double) lectures. During the 2nd and 3rd offerings the Danish lectures were recorded as two sub-videos – one before and one after the (main) break. The disadvantage of these relatively long videos is that since the entire desktop is shared in the meeting room (as opposed to just a single specific pdf or Powerpoint presentation), the recording includes no option for the viewer to easily jump from subject-to-subject within the video. This is why in the 4th offering during spring 2011, the recordings were carefully planned to be “stopped-and-restarted” following the subheadings of each individual lecture. A double lecture of 90 minutes would then be recorded as 4-7 video clips providing a subject based video-clip collection of the entire course – all together around 70 video clips of around 18 minutes length on average, cf. [3].

In Table 1 the statistics on how many times these videos have been viewed (or at least started viewed) is given. During 2010 (1 Feb 2010 – 1 Feb 2011) there was almost 10.000 hits on the entire collection with around 9.500 of those on the introductory ones. During Feb-March 2011 the hit number was around 3.000, which means that (in writing) 50 times every day of the week someone starts to watch one of the introductory statistics lectures.

Table 1
Video hit statistics. Numbers are accumulated number of hits as reported by the Adobe Connect video report feature.

	01.02.10	02.02.11	04.04.11
02402 F08 (10 x 90min)	3111	3915	3915
02402 S10 (20 x 45min)	0	3497	3634
02402 F10 (23x45 min)	0	778	811
02402 S10 Eng (15x75min)	0	4409	5124
02402 S11 (70x18 min)	0	46	2117
02429 F10 (25x30 min)	0	230	230
27411 S11 (13x40 min)	0	0	80
Miscellaneous (7x45min)	0	223	268
	3111	13098	16179

COURSE EVALUATION

The courses were evaluated by the students as any other course at DTU, that is, using standardized questionnaires with no specific questioning related to the new teaching approach. In writing, the 4th course offering during the spring of 2011 is not yet finished, so no evaluation information is accessible. Also, as the more interactive use of the meeting

room really only had an impact during this latest offering of the course so the evaluations reported here would include no information about this part. One of the questionnaires asks for qualitative comments from the students using the questions:

What went well – and why? (Question 1.1)

What did not go so well – and why? (Question 1.2)

In Table 2, some statistics are given on these two questions. Among the 20 negative comments in all three courses (847 students) only two comments in the first version of the course specifically was about the writing on the tablet as an alternative to the blackboard. And there was 5 students specifically mentioning this as a positive thing.

Table 2
Student evaluation of courses

Course	No. of participants	No. of respondents	No. of 1.1 comments	No. of Video positives	No. of 1.2 comments	No. of Video negatives
Fall 2008	350	184	87	38	60	14
Spring 2010	187	61	22	10	15	5
Fall 2010	310	136	40	11	23	1

The one negative comment in the Fall 2010 (and one of the 5 in the Spring 2010) was by one of the English speaking students who ONLY get lectures online. And the comments were exactly about the fact that they did not have access to real life contact with the teacher during the lectures. In each version of these two courses 15-20 other non-Danish speaking students did NOT comment on this. In the first version four of the negative comments were general criticism that the university was not able to provide a room large enough for everyone (which by the way is not a quite fair criticism, since with the turn up percentage common for this course the room WAS big enough for everyone). And the remaining negative comments were all about the times when the technical details were giving trouble. All in all not many comments even about that – and in the latest version of the course NONE what so ever about this. The decrease of the number of positive comments could in a way also be given a positive interpretation: If everything around the recordings and the use of the tablet computer for teaching is just working smoothly it shouldn't be too much in focus, and hence there is no reason for giving any particular comments on that.

DISCUSSION AND FUTURE PERSPECTIVES

The possibility of inviting people in to listen to (live) lectures even though they are at a different location has some obvious benefits. The same goes for the possibility of subsequent sharing of the recorded lectures. This will provide access to the lectures for individuals that otherwise would not have had this access, be it regular students that was hindered due to illness, travelling, elite sports activity or whatever reason, external research partners from industry and/or other research institutions or students from other courses – the list would be endless. A collection of statistical video lectures could be an important part of the ability to offer individual adapted courses, especially important for PhD education within those many non-statistical fields where statistics plays an important role in research. The same goes for the development of continuing education course activity. Similarly, the collection of videos may serve as part of the ongoing awareness and recruitment challenge for our statistical education and/or our role as important collaborator in research projects.

Apart from this, what potential impact, positive or negative, these extended possibilities have on the behaviour and learning process of the “regular” student in the introductory statistics course 02402 is not 100% clear. The same goes for the potential impact of the attempts of making the large audience lecture more interactive by the use of the meeting room features such as chats and polls. When more advanced applications for iPhones and Android phones are ready, and participants can join this way enjoying (close to) full use of all the meeting room features instead of having to use a laptop (and avoid any external and additional physical poll systems), there is an even larger potential for creating interactivity around the lecture participation. It will be a pedagogical challenge, but if used properly it is the clear conviction of the present author that it can enhance the value of the otherwise maybe somewhat old-fashioned large audience lecture.

So far the student behaviour in these courses has not been monitored in any way (apart from being able to count the number of students in the lecture room together with the corresponding number in the exercise rooms). An idea for the future would be to setup an investigation to clarify this, that is, by a questionnaire or in some other way trying to identify exactly how the individual student behaviour really is. And then link this information on the individual level to course evaluation data and to the final course grade result. This could provide some important information on the real impact of this novel teaching approach.

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Biographical Information

Per Bruun Brockhoff is Professor in statistics at DTU Informatics at the Technical University of Denmark (since 2004) and Head of the Statistics Section (since 2008). He was the Chairman of DSTS, the Danish Society for Theoretical Statistics (2003-2007), and Chairman of the International Sensometrics Society (2006-2010). Professor Brockhoff co-authored around 60 peer reviewed scientific papers and 2 books and is an elected member of ISI (International Statistical Institute) (since 2005). He has 16 years experience in planning and teaching large audience introductory statistics courses together with other courses.

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Kanazawa Technical College

ABSTRACT

Kanazawa Technical College (KTC) is one of the newest members of CDIO. It is also the first institution in Japan to join CDIO as a Collaborator. Since applying for and receiving a grant in 2007, KTC's Mechanical Engineering department has led the school in educational reform by reviewing and enhancing the curriculum to ensure its students have all of the skills both necessary and desired for industry upon graduation. Through this process, the "Creative Design" series of courses were developed and instituted. They conform to the CDIO Syllabus and Standards more closely than any other courses currently offered, so KTC has started benchmarking and analyzing its curriculum with these courses. Additional courses and departments will follow, but due to the cultural and language differences, adoption will be a slow process. Stakeholders will be involved throughout the curriculum enhancement process and current survey practices will be used to understand how KTC education as a whole compares to the CDIO Syllabus. Many documents and tools provided by CDIO are still being understood and translated, such as ITU assessments, and will be used in the future to assist with curriculum integration. KTC is also assisting additional institutions to learn about and join CDIO as future Japanese collaborators.

KEYWORDS

hands-on education, CDIO Standards Evaluation, Adopting CDIO, CDIO Japan

PREFACE

Japan's industrial sector has faced many challenges in recent years. Some of the challenges include reduced competitiveness in the international arena, an educational focus on theoretical rather than practical knowledge [1], and an ever-increasing average age in small and medium sized enterprises [2]. Many companies have a global presence and must adapt to working with people from other cultures. In addition to industrial problems, Japan's birth rate has been declining [2]. Some of these problems can be addressed through a re-examination of technical education in Japan.

Since recognizing these problems, Kanazawa Technical College (KTC) has been studying the technical education provided to students. With a grant from the government, KTC has created and implemented a Project Based Learning (PjBL) curriculum component. This program introduces students to hands-on manufacturing techniques and the product development lifecycle as well as cultivating management ability in graduates. This group of courses, one full year course per year level, is called "Creative Design" and forms the backbone of the hands-on curriculum at KTC. Considering the success of this program as well as results from stakeholder surveys, KTC petitioned to join CDIO in 2010.

This paper will discuss the current state of engineering education in the Mechanical Engineering Department at KTC, specifically, the hands-on course sequence, as well as what KTC is doing to adopt CDIO in Japan.

CREATIVE DESIGN

Creative Design is a hands-on program designed to cultivate the overall skills and abilities of students by incorporating disciplinary knowledge, personal and interpersonal skills, as well as technical know-how individually and in teams for students of all year levels. Assessment techniques include portfolios, presentations, as well as milestone deliverables and tested final products. Students take on various roles in teams and engage in Conceive, Design, Implement, and Operate experiences as well as evaluation of self, group, and peers through hands-on projects that enhance students' problem solving and leadership abilities. Students are also exposed to project management tools and techniques especially in the fourth year when they are expected to design and build a robot, to create and follow a schedule, create a comprehensive bill of materials, and work within a budget in order to complete their robot on time and within required parameters.

Approach

The Creative Design series of courses in their current incarnation were developed through a grant from the Japanese Ministry of Education (MEXT). Project based learning (PjBL) was used as the basis for these courses, as well as the Plan-Do-Check-Act model to build on students' skills each year [3]. For the first three years, students work on projects that are heavily Implement-oriented, with some Design work where appropriate, to teach them how to use various tools in the machine shop and guide them through creating finished products that are guaranteed to be successful in order to build students' confidence in their work and guide them in learning necessary skills for later courses. For their fourth and fifth years, students are given projects that can run the gamut from Conceive through Operate.

The fourth and fifth year courses also integrate many personal and interpersonal skills such as project management, presenting and defending their engineering decisions to not only their peers and professors, but also to local representatives from industry, as well as working in teams to complete a project with scheduling and budgetary requirements. Students build

on their disciplinary knowledge and hands-on skills beginning with the technical fundamentals, applying what they have learned, developing products from start to finish, and finally many students partake in applied research as their fifth year capstone project. The fifth year capstone course is highly individualized, with teams participating in national and international technical competitions and students participating individually or in small groups in industry sponsored research or taking their own or a faculty advisor's ideas as the basis for their projects. This course will not be discussed as its content is highly variable.

Creative Design I

Creative Design I acts as an introductory course to KTC and to engineering. Students are introduced to campus policies and procedures as well as major-specific information and general skills that will help them in their academic career such as good nutrition and effective study habits. After the initiation into life at the Technical College, students are separated into two groups. One learns how to use the various machines in the machine shop while one group studies drafting. The groups trade places when the module finishes. During the second semester, students use the plans they have drafted and the machines they have been introduced to in order to create a calligraphy paperweight with a handle that screws into the base. The other half of the class studies bridges and creates a balsa wood bridge, testing how well the trusses hold weight, before trading places to finish the term. Students end the year with a good general understanding of the machine shop, basic drafting and design, and statics.

This course focuses heavily on Implementing, with some Design in well-defined areas. This course deals mostly with introducing students to the processes and ideas of hands-on projects, and has minimal personal and interpersonal skills integration. Students design the trusses of the bridges they build as well as the cross-section and handles of their paperweights, as seen in Figure 1:

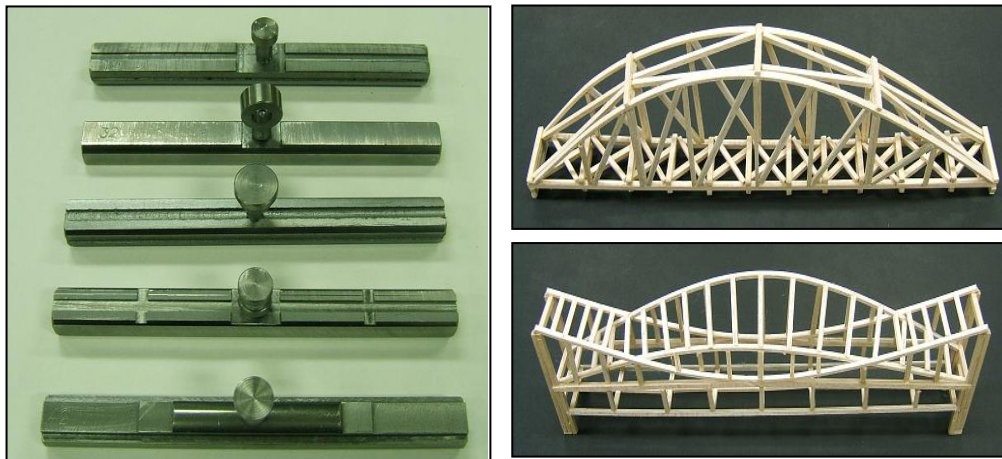


Figure 1. Creative Design I Projects

Creative Design II

In Creative Design II, the class is divided into three smaller groups and each group takes part in three ten-week courses. One experiment-based course focuses on springs, where students make their own spring and test it using various methods. The second section deals with electronics; the students learn how to solder and build the electrical components of a line tracing car with various sub-steps, including a light-powered car. The final section teaches students the principles behind gyroscopes and brings them back to the machine shop to build their own, competing to see whose will spin the longest.

This course is mainly guided Implementation and experimentation. There is little independent Design; students are typically asked to utilize the given tools and parameters to find the solution to problem with a single solution. Examples of the projects can be seen in Figure 2:

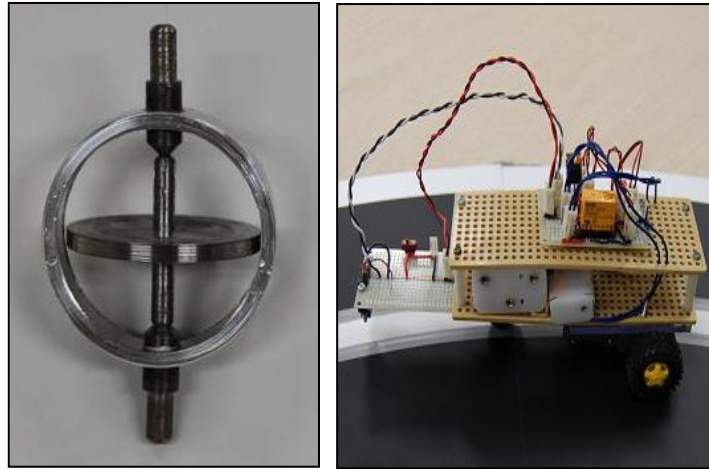


Figure 2. Creative Design II Projects: Gyroscope and Line-Following Car

Creative Design III

This course is a mechatronics course. Students are given line-following robots from the year before. They determine whether or not the cars were successful, then consider what modifications, if any, should be made to create a better robot in terms of operations and ease of machining. The robots all have the same bill of materials, but the specific dimensions of individual components can be modified. Students revisit skills and techniques they have used in earlier courses to complete their robot while adding aspects such as CAD drafting, CNC machining, and making design decisions.

While this course is mainly an Implement course, there is some Operation in the design modifications students make at the beginning and the analysis students provide at the end of the course. There is also some Design utilized in improving the prior years' model, which is used as the template for the robot they will make. In addition, students build on personal and interpersonal skills by sharing initial work in pairs and presenting the results, including design and manufacturing optimization suggestions, to the class.

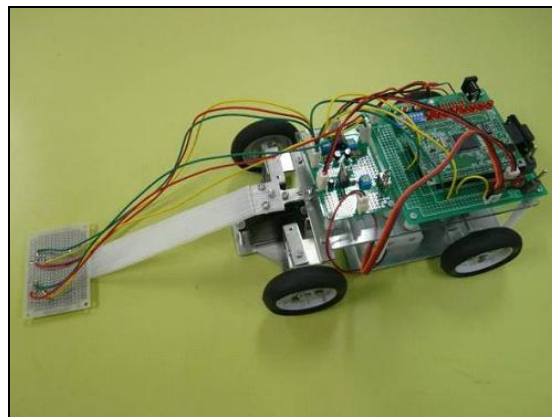


Figure 3. Creative Design III Line-Following Robot

Creative Design IV

For their fourth year, students are separated into groups of six or seven students. Each group builds a line-following robot that must perform, activating multiple mechanisms, at

specific points around a given course. The teams split into subgroups of two to three students working on the three main aspects of the robot: mechanisms, control, and structure. In addition, a team leader is chosen to manage documents and a second-in-command is named to assist with overall group documentation and management. The students keep portfolios, give presentations, and deal with project management aspects such as scheduling, time management, and budgeting.

This course has the strongest connection to the CDIO Syllabus. The students Conceive, Design, and Implement, as well as consider some aspects of Operation, while integrating a large number of personal and interpersonal skills through their project. Each team exercises not only disciplinary skills but also creativity in choosing a theme for their robot, mechanisms that match the theme, and explaining through presentations what their theme is and why they have chosen it. An example, a penguin robot that has a party whistle in its mouth, can be seen in Figure 4:

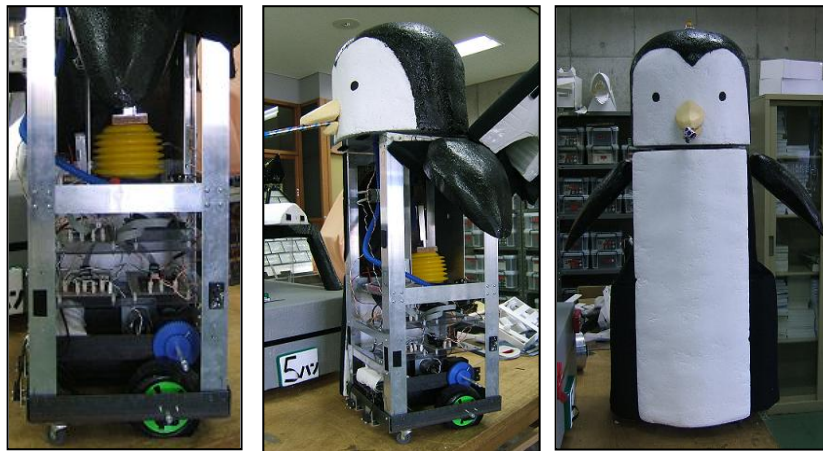


Figure 4. Creative Design IV Robot

ADOPTING CDIO

The most significant challenge for KTC in adopting CDIO throughout the curriculum is the language barrier. CDIO documents do not yet exist in Japanese, and as the first Japanese institution to join as a Collaborator, an effort to understand and correctly translate the nuances of the Standards [4] and Syllabus [5] must be made. Many common words and phrases, especially in the areas of engineering and education, take on a slightly different meaning when appropriated by another culture. The word “research”, written as “リサーチ” and pronounced “resaachi”, for example, simply means finding the answer in Japanese, as opposed to the Merriam-Webster Dictionary definition of “1: careful or diligent search, 2: studious inquiry or examination; especially investigation or experimentation aimed at the discovery and interpretation of facts, revision of accepted theories or laws in the light of new facts, or practical application of such new or revised theories or laws, 3: the collecting of information about a particular subject” [6]. Some of the Standards, including the Context and Learning Objectives, have not been translated but rather are going to be used as-is because there is no direct Japanese translation. One concern will be to keep the original, intended meaning intact.

In addition to language and cultural differences, KTC is one of Japan’s sixty-three Technical Colleges. A Technical College is a five-year program combining the three years of high school with two additional years of higher education, as seen in Figure 5 [7]. This allows students to either transfer to typically the third year of a four year institution or enter the job market upon graduation. The class structure is very rigid, with students taking all of their core

and disciplinary courses at the same time. While this does limit flexibility for students' personal strengths, weaknesses, and learning interests, it offers a greater ability to integrate the curriculum as all teachers know exactly what courses their students take and with which professors. Up to this point, however, collaboration has not been a part of the curriculum and so will be a later implementation.

College of Technology System

KOSEN — five-year engineering education from 15 years old.
After graduating from KOSEN, most students go to advanced universities or Advanced Courses (AC) of Colleges, while the others find employment.

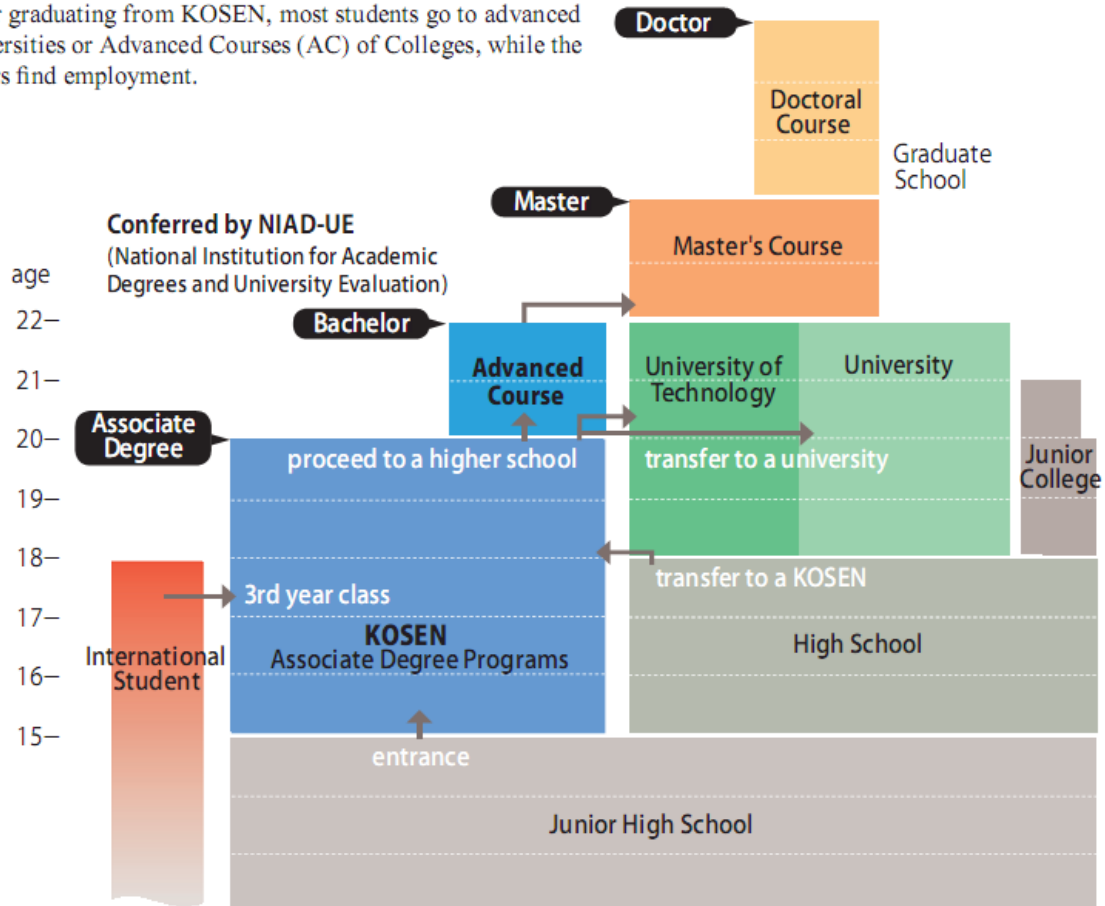


Figure 5. Japan's College of Technology System [7]

Stakeholder Evaluation

The opinions of stakeholders are important in shaping graduates who are ready to enter industry, well prepared for what will be expected of them. Surveys of students and faculty are performed yearly, and recent alumni along with partners in industry are surveyed every five years. The corporate survey asks about not only the proficiency of KTC graduates but also the expected proficiencies for new employees [8]. Students who have graduated since the last survey was given are asked how well their education is serving them as well as what areas have been found to be lacking in order to understand the strengths and weaknesses of their KTC education [8].

The most recent survey, performed in 2009, included the following questions (translated from Japanese) regarding specific student skills:

1. Research
2. Organization of Research

3. Critical Thinking
4. Ability to Understand Others' Perspective
5. Problem Formulation and Hypothesis Creation
6. Autonomy
7. Communication
8. Articulation of Opinions
9. Leadership
10. Empathy
11. Curiosity
12. Initiative
13. Perseverance
14. Honesty
15. Common Sense
16. Social Responsibility
17. Disciplinary Knowledge
18. Application of Disciplinary Knowledge
19. International Communication (including written and conversational language skills)
20. Computer and Internet Abilities
21. Career Planning
22. Ethics

While this survey was not created with the CDIO Syllabus in mind, as do typical stakeholder surveys implemented by CDIO institutions [9], it does involve many of the aspects of the Syllabus already. By adopting the CDIO Syllabus, areas that are known to be deficient can be better served and areas that had not been considered, but are important in engineering education, can be addressed. In particular, KTC ranks lowest in leadership and English language communication. While the majority of the stakeholders surveyed have similar opinions about the abilities of KTC graduates, the faculty tend to have a much lower opinion across the entire range of skills surveyed, as seen in Figure 6:

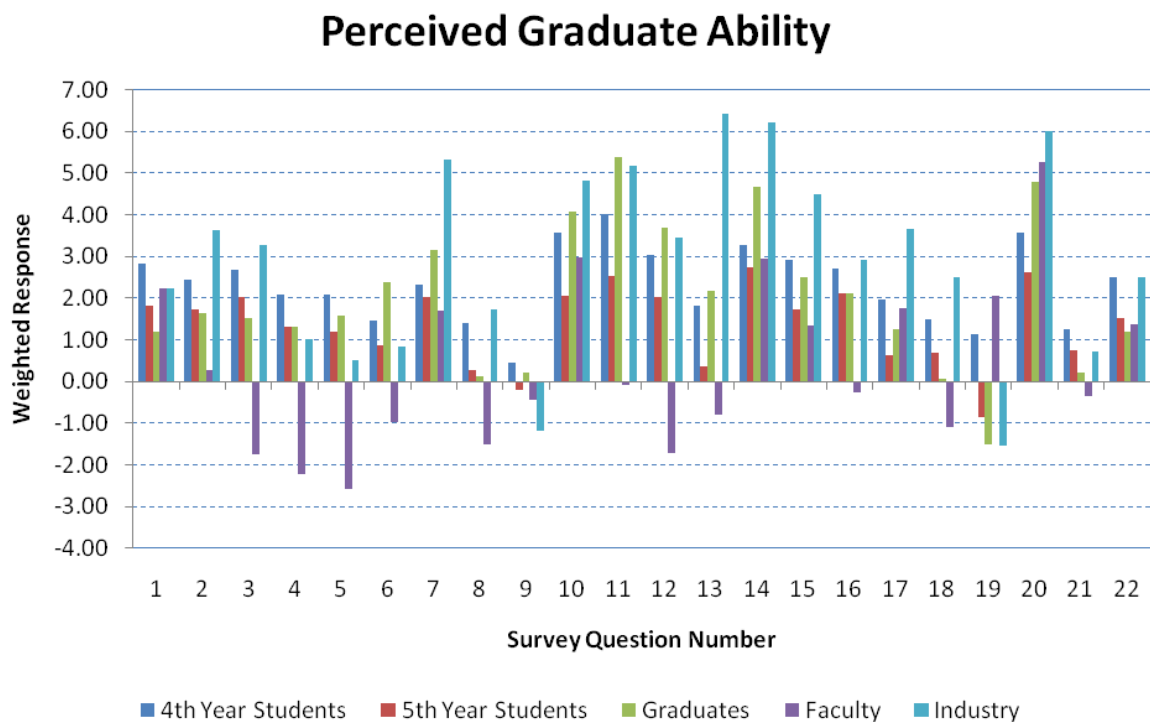


Figure 6. Perceived Graduate Ability, various stakeholder groups surveyed [8]

The courses that are already highly compliant with the CDIO Syllabus, the Creative Design hands-on courses, tend to have the highest student approval ratings among Mechanical Engineering students when compared to other courses taken by ME students as well as compared to the hands-on classes in other majors at KTC as seen in Figure 7:

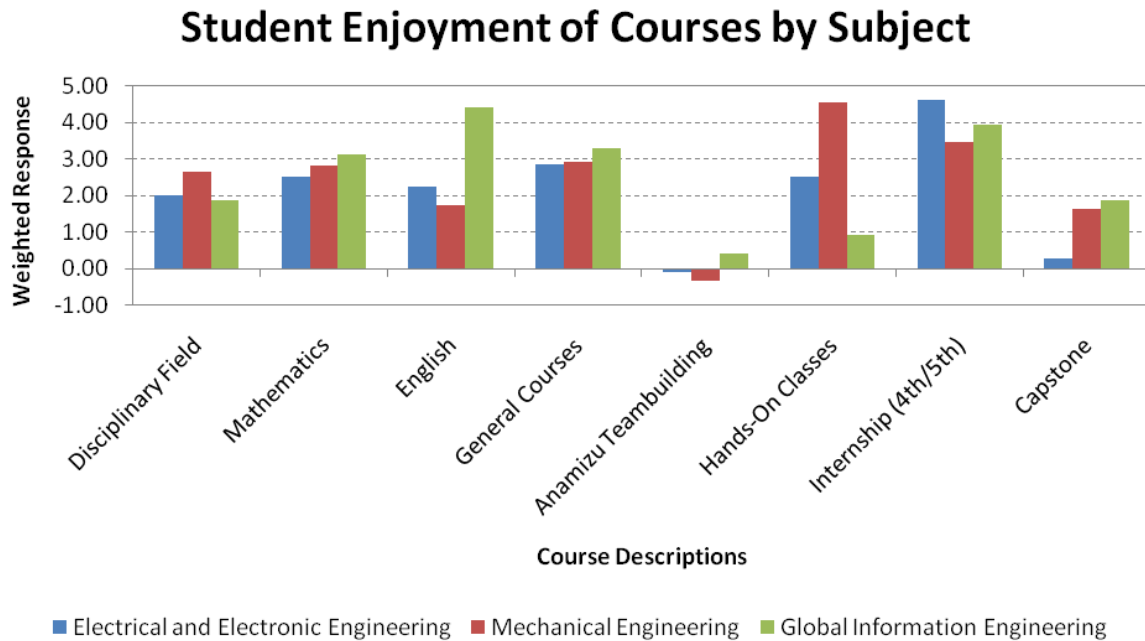


Figure 7. Student Enjoyment of Courses by Subject, separated by major [8]

As other courses are modified based on the CDIO Standards and Syllabus, it is believed that enjoyment of courses will increase. While student enjoyment of courses is not the main reason for adopting CDIO, students are more likely to succeed if they are interested in the coursework and subject matter.

FUTURE DEVELOPMENT

Once a final translated version of the main CDIO documents are completed, benchmarking tools will be translated and implemented, such as ITU charts and surveying the faculty to see which areas of the Syllabus are used in class [4, 10]. When benchmarking is completed, the Creative Design III and IV courses will be modified to include more aspects of the CDIO Standards and Syllabus. Once the Mechanical Engineering department has begun implementing CDIO, the Electrical and Electronic Engineering and Global Information Engineering departments will take the best practices found by the Mechanical department and begin adopting CDIO as well.

Through industrial trade fairs, conferences, and other venues both formal and informal, KTC will introduce more Japanese institutions to the CDIO approach and methodology. The Kanazawa Institute of Technology hopes to become the first university in Japan to join CDIO and is working with KTC to better understand the program and its requirements. Additional institutions have already shown interest in adopting CDIO as well; KTC will be assisting any that decide to pursue a CDIO curriculum.

CONCLUSIONS

As the first institution in Japan to join as a Collaborator, KTC is beginning to translate and interpret the CDIO documents for Japanese language as well as Japanese educational and cultural differences. In order to correctly adopt CDIO, this process will be slow to ensure all educators and policy makers are able to understand the CDIO methodology. In addition to working with the documentation, benchmarking and stakeholder surveys are being undertaken to understand, through the lens of CDIO, where KTC currently stands and to identify areas for improvement. While KTC has a strong program of project based classes focusing heavily on Design and Implementation, other areas of the curriculum are lacking in depth of learning and breadth of teaching and assessment methods. Once a full assessment of departmental curriculum and policies has been made, testing and implementation of new techniques will begin.

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AN EVALUATION OF ACTIVE LEARNING STRATEGIES APPLIED TO ENGINEERING MATHEMATICS

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ABSTRACT

An engineering mathematics module has been developed and implemented to promote deeper learning using the CDIO methodology. It conforms to several CDIO Standards and also seeks to develop personal, interpersonal and professional skills through an active and interactive learning paradigm. This paper discusses the content, pedagogy and efficacy of the module in relation to student motivation, engagement and attainment over a three year period. It is shown that such an approach is successful in this regard.

KEYWORDS

Engineering mathematics, active and interactive learning, computer assisted assessment (CAA), computer aided learning (CAL), web-based learning, virtual learning environment (VLE), Helping Engineers Learn Mathematics (HELM).

INTRODUCTION

The School of Mechanical and Aerospace Engineering at Queen's University Belfast (QUB) is striving to improve its student learning experience. A curriculum change plan was already being developed when the School became a collaborator in the CDIO Initiative [1] in 2003. This is an innovative educational framework that provides students with an education stressing engineering fundamentals set in the context of Conceiving, Designing, Implementing and Operating (hence CDIO) real-world systems and products. In 2004 the School introduced a new Product Design and Development (PDD) degree programme which was designed entirely on this CDIO ethos. Extensive experience was gained in researching, developing and implementing the mathematics provision for this new PDD programme as the entry requirements were not as stringent as the School's other engineering programmes with regard to mathematical skills; an A-Level mathematics qualification was not required to enrol on the new PDD programme. In addition, there was originally only one engineering mathematics module scheduled in the new programme (for first year students), and this one module would therefore need to equip the students with the prerequisite mathematical skills necessary for all the other scientific and analytical modules in the whole PDD programme. The success of this single mathematics module would therefore be paramount for successfully graduating this programme.

The planning, design, preparation and implementation of this first year module, and specifically the assessment strategy employed, are described in detail by the authors in previous publications [2,3]. It was recognised that teaching mathematics to engineers is a worldwide issue, evident by the extent of published work on the topic. However, to conform to the programme ethos, the CDIO Standards (p35 of reference [1]) were carefully applied to developing this module using a systematic method, supported where possible by the best current pedagogical practices.

In such a teaching environment it was important to ensure that this mathematics module could integrate with the rest of the course and espouse the same learning strategies inherent in the other more design orientated modules (Standard 7), which was considered essential if the students were to stay motivated and engaged throughout. Relevant learning outcomes, skills and attributes were identified by applying an ordered approach to course design [4] and the content was finalised by conducting interviews with all the teaching staff on the programme. The teaching methods were varied to facilitate active and interactive learning in class (Standard 8), which simply allowed the students to individually or collectively work on problems and then present their results [5]. In addition, an effective assessment strategy was implemented to promote and encourage out-of-class active learning [3]. It is worth noting that all engineering mathematics modules are taught “in-house” by staff from the School.

Although this first year mathematics module was very successful based on qualitative and quantitative feedback, attainment and attendance data, further evaluation of the module and other subsequent scientific modules provided evidence that more needed to be done to help further student learning with regard to mathematics. This paper describes the rationale behind developing another mathematics module for second year PDD students, based on providing more practice, analysis and relevant application of the learning outcomes of the first year module, and aiming to maximize student engagement and promote deeper learning through extensive deployment of active and collaborative learning techniques. In addition, implementing the CDIO methodology with regard to module design should consider all possible learning opportunities for developing not only technical skills and attributes, but also non-technical skills such as personal, interpersonal and professional skills [4]. So this was the guiding axiom in the choice of pedagogy for the new module.

A variety of pedagogical techniques were investigated: the use of relevant engineering applications, online resources, computer-aided assessment with instant feedback, and computer modelling, analysis and simulation assignments. The pedagogy implemented in this module is discussed in detail in the following sections and the efficacy of the endeavour is presented over a three year evaluation period along with data relating to the students' motivation, engagement and attainment in the course. In addition, some practical issues relating to delivering such an engineering mathematics module are discussed.

RATIONALE FOR A SECOND YEAR ENGINEERING MATHEMATICS MODULE

A diagnostic test is given to all students at entry to the PDD programme to determine their levels of proficiency in mathematics and target them for support. After two years of evaluating the first-year mathematics module, it soon became evident that those whose mathematical skills were weakest at entry to the PDD course were struggling to achieve the intended learning outcomes and were going to need more tuition, guidance and practice. There were several factors that helped formulate this conclusion: Active learning sessions; Homework/tutorial sheets; Examination; Second diagnostic test.

The first-year mathematics module includes active learning sessions or “tasks” within the lectures [2] that provide excellent feedback to the lecturer and the students on their achievement of the intended learning objectives. As part of its assessment strategy a

proportion of marks are allocated to coursework and continual assessment. This has improved learning on the module [3] and feeds-back as instantaneous data to the students and the lecturer regarding their progress.

Therefore, information was continually acquired that identified specific topics in the first-year mathematics module where the students particularly struggled to achieve the intended learning outcomes. To corroborate this evidence, a second diagnostic test was carefully designed, based on these topics, to precisely highlight these perceived problem areas. This test was given to the first year PDD students after the mathematics module had finished and further validated what was already evident in relation to the students' perceived difficulties with the intended learning outcomes.

As part of the School's module evaluation strategy, formative feedback was also received from the students that indicated the need for more practice and support to better enhance their mathematical skills. Action had to be taken and the preferred solution was to provide another mathematics module in the second year of the PDD programme which would focus on developing self learning, analysis and simulation skills through the practical application of mathematics to relevant problems.

DEVELOPMENT OF SECOND ENGINEERING MATHEMATICS MODULE

The main objectives for this new second-year engineering mathematics module were simple:

- Provide more practice in specific mathematical methods presented in the first year course.
- Promote a deeper learning environment.
- Encourage self learning.
- Further emphasise the relevance of mathematics through analysis and simulation.
- Exploit the development of other non-disciplinary skills relevant to the CDIO syllabus.

The development of the first-year mathematics module was founded on investigating the current best practice with regard to learning and teaching in the field of engineering mathematics. Therefore, it was deemed essential that this same ethos was applied to developing the new second year module based on the clear objectives above. As such, all pedagogical decisions for the new module would be based on sound, established theory and practice as discussed in the following subsection.

Current Pedagogy on Teaching Mathematics to Engineers

Today, teaching engineering mathematics at tertiary level is all about providing adequate support. The two main reasons for this are: Students' mathematical skills at entry to university [6]; and students' lack of ability to apply mathematical knowledge [7].

In the UK over the past ten years there has been a great deal of investment in research projects to support the teaching of engineering mathematics. In 2001 Croft and Ward [8] described the aforementioned problems facing the teachers of tertiary level engineering mathematics and espoused a "modern and interactive" approach to ensure deeper learning. They explored Computer Aided Learning (CAL) as one such way to motivate and encourage students by providing instant feedback on their progress. They advocated a learning environment that also exploited continual learning outside the class which was achieved by implementing credited Computer Aided Assessment (CAA) [9]. However, they stipulated that such an approach requires special, well equipped workspaces. Golden and Lee [10] also promoted the use of web based resources to support the teaching of engineering mathematics by encouraging "reflective modes of study" and engagement with course material. More recently, Janilionis and Valantinas [11] further emphasised the importance of virtual learning environments (VLEs), CAA and software applications to produce more

attractive learning experiences. They encouraged their students to develop non-technical skills and attributes, such as logical thinking and problem solving skills, which conforms to the CDIO methodology regarding module planning [4].

This proven pedagogy therefore provided the impetus for the way forward for the new second-year engineering mathematics module. To meet its objectives, the content of the module would focus around web-based resources, CAL, CAA and relevant simulation tasks and assignments.

MODULE CONTENT

The content of the new second-year module was based around the assessment strategy, which consists of two specific areas:

1. Computer assisted assessment (CAA) using the HELM [12] Learning Resources.
2. Analytical design assignments in Microsoft Excel.

This strategy involved continual assessment and coursework, but no final exam. The HELM Learning Resources and the resources from the first-year mathematics module were made available to the students on the School's VLE. A CD containing the HELM resources was also given to each student so that they would always have access to this learning environment.

Computer Assisted Assessment (CAA) Using the HELM Learning Resources

There were four mathematical topics included in the learning outcomes for this second-year engineering mathematics module: Basic Algebra; Equation Manipulation; Trigonometry; Basic Calculus. Remember that the majority of the PDD students enrolled for this module would not have a Secondary qualification in mathematics (A-level) and these topics related directly to the learning outcomes from the first-year module and also the HELM workbooks and CAA. For each of the four topics above the students were given three weeks to work through the HELM CAA self-testing regime with the proviso that there would be a class-test at the end containing exact examples from the self-tests they had just completed. Each class in this three week period used mini-lectures, tutorial-like sessions and group discussions to support the HELM material. The class tests at the end were paper-based, lasting no more than thirty minutes. The papers were marked and returned to the students in the following class for reflective purposes and any unresolved learning issues relating to the respective mathematical topics were dealt with in that class. Obviously, the workspace associated with this type of learning environment had to comply with these specific teaching methods being implemented.

Analytical Design Assignments in Microsoft Excel

The benefits of using simulation assignments to promote learning in engineering mathematics, while simultaneously developing other personal, interpersonal and even professional skills, were discussed earlier, referencing key pedagogical papers. The new second-year engineering mathematics module contained three such assignments. For logistical reasons, Microsoft Excel was chosen as the medium to graphically solve the real-life analytical design problems defined in the assignments; the students were already relatively familiar with Excel, but had little experience in actually applying it to a mathematical analysis and simulation scenario. It was essential to clearly define the deliverables for these assignments and describe the problems carefully and in detail so that the students understood what was required. This ensured the students were confident in their approach to the assignment and also cultivated a sense of achievement on completing it. Continual feedback on their progress during the assignment, and at the end, was also crucial to their

appreciation and even enjoyment of the task. All assignments were marked and returned to the students before the next assignment was given.

MODULE EFFICACY

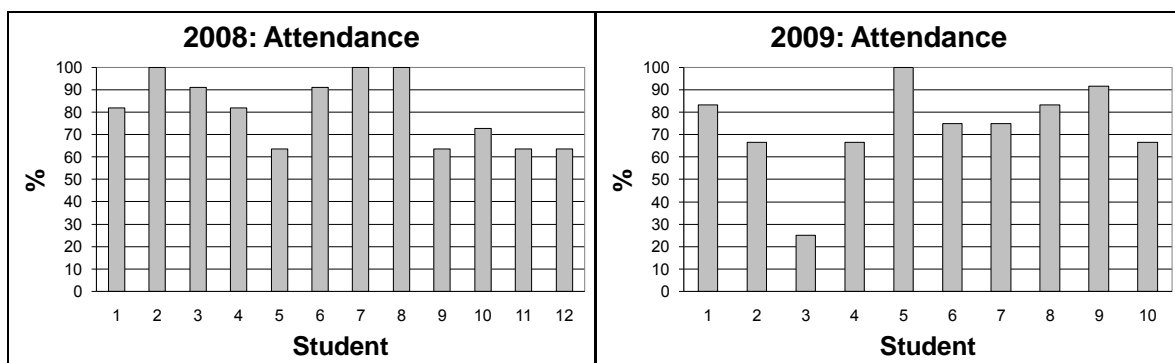
This section provides a detailed evaluation of the new second-year engineering mathematics module in the form of both summative and formative data over a three year period between 2008 and 2010 inclusive. In addition, and most importantly, in 2010 a ‘before and after’ diagnostic investigation was performed to verify that this module was indeed augmenting the students’ mathematical skills and knowledge. The module objectives are discussed in relation to student engagement, motivation and attainment.

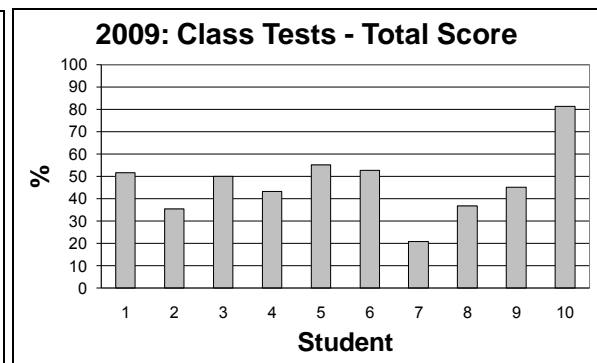
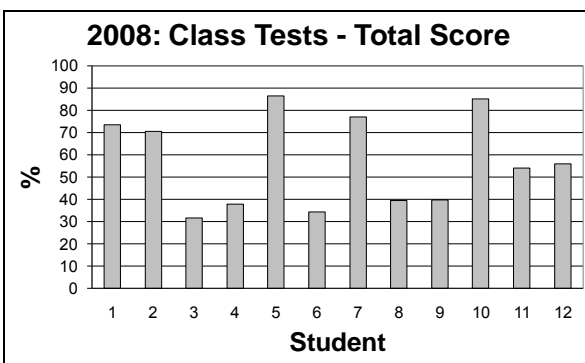
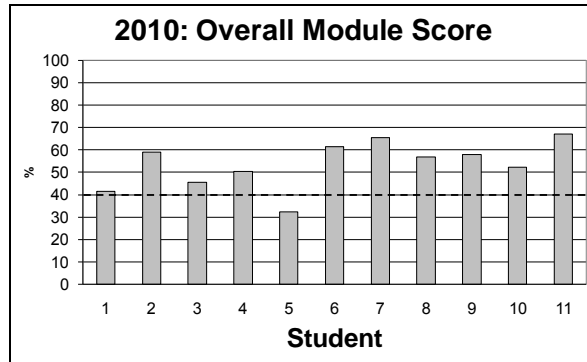
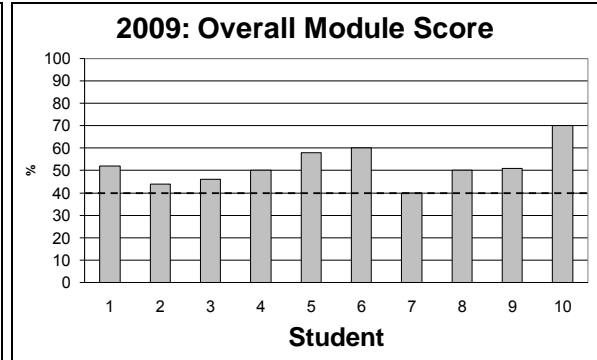
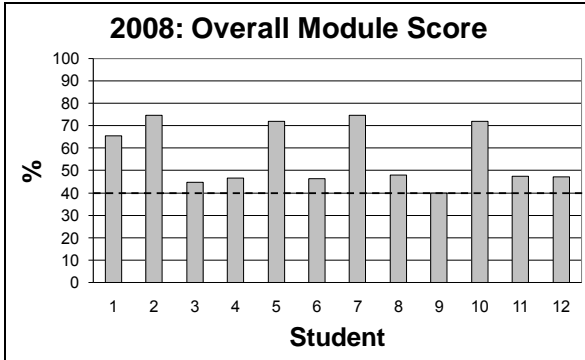
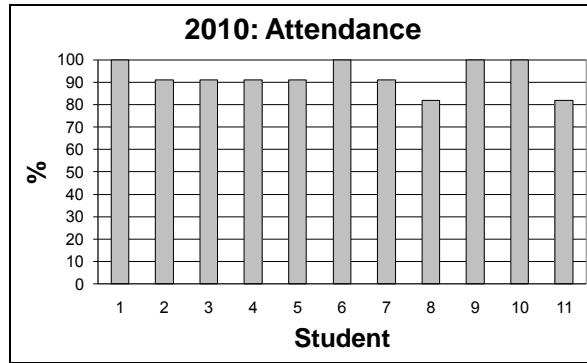
In 2008, 2009 and 2010 there were twelve, ten and eleven students respectively enrolled on the module, which certainly facilitated the implementation of the active and interactive teaching and learning methods referenced and instigated. Attempting this with a larger class would have required more teaching resources, including bigger workspaces, more postgraduate demonstrators and more computers. Obviously, the provision of timely and relevant feedback would also require more time and effort due to the inherent increased assessment workload associated with bigger classes.

Assessment Results

The summative assessment results are illustrated in the graphs displayed in figure 1. In each of the graphs the x-axis represents an individual student in the class, numbered 1 to 12, 1 to 10 and 1 to 11 respectively for each cohort year, and is kept consistent throughout. There were three hours of contact time per week in the twelve week semester and it can be seen from the “Attendance” graphs that the average attendance was 81%, 71% and 93% respectively in 2008, 2009 and 2010.

The graphs of “Overall Module Score” show that no-one failed the module (the marks for student 5 are discounted due to external extenuating circumstances affecting their performance) and that the average score was a credible 57%, 52% and 54% respectively (pass mark 40% - dashed line). However, the graphs of “Class Tests” and “Assignments” show a respective breakdown of the overall module scores, where it can be seen that 33%, 30% and 27% of the respective cohorts failed the class-tests, but all students passed the assignments in each year. It seems that the assignments may have provided a more balanced platform of learning as there was less deviation in the marks, but it must also be considered that the students were potentially less motivated and more strategic in their approach to the class tests.





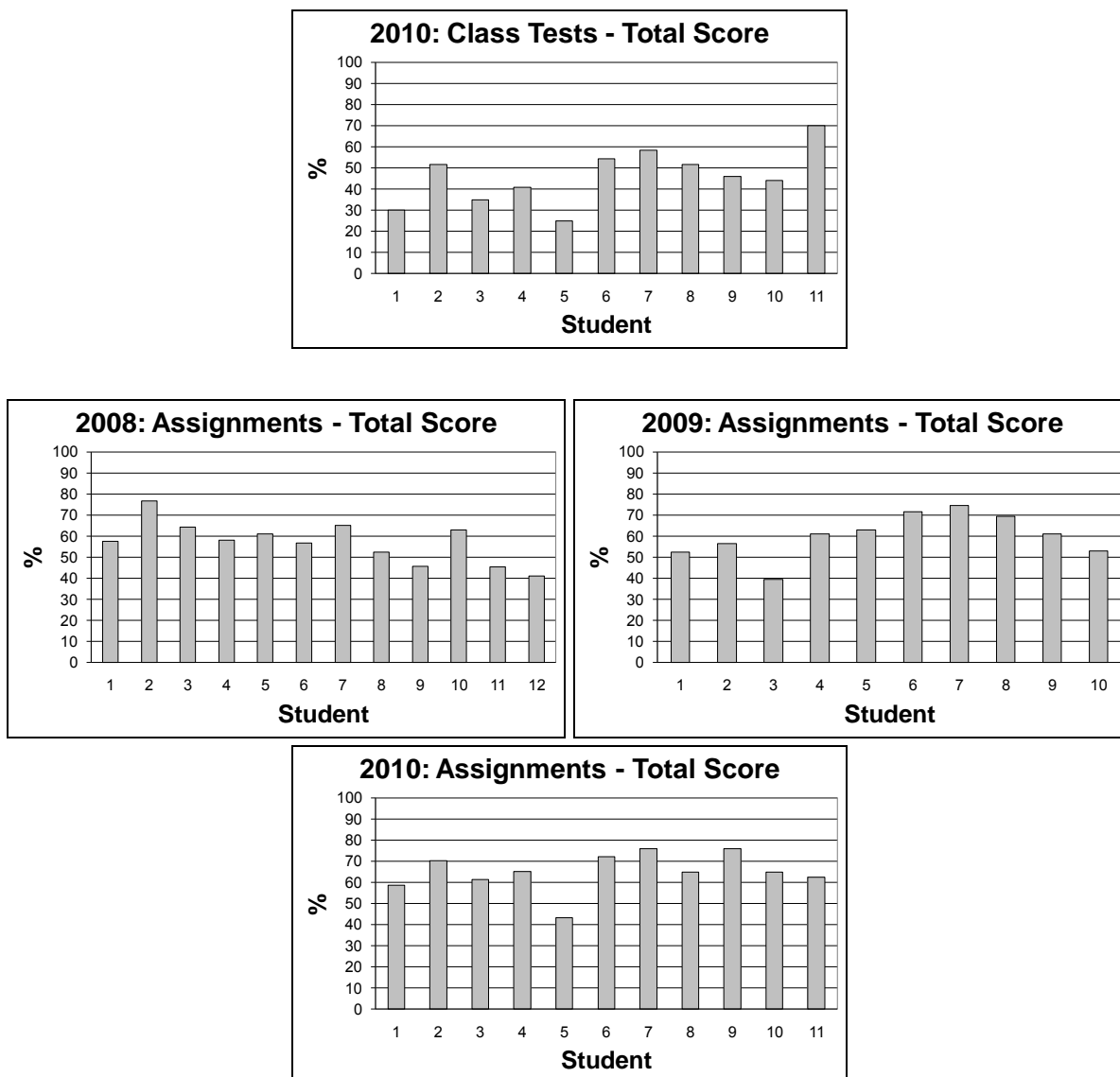


Figure 1. Summative assessment results for the new engineering mathematics module

One of the advantages of the teaching and learning methods employed on this module is that the lecturer/instructor gets to know the class very well due to all the interaction and discussions involved, and soon builds a detailed understanding of each student's individual abilities and attitudes. It was evident over the three cohorts that some students were very strategic in relation to their attendance and engagement with this module, doing just enough to pass and stay within the boundaries regulating it, and some students had excellent attendance, but their overall module scores were less than 50%. In this latter case, the students had also struggled on the first-year engineering mathematics module and had modest mathematical backgrounds on entry to university. Their performances in the class-tests and the assignments, as shown in the relevant graphs in figure 1, revealed an intriguing story - they performed poorly in the class tests but much better in the assignments in relation to the other students. However, it was evident from their engagement in-class that they appeared to enjoy the assignments more than the formal study, self learning and practice for the class tests.

At present, 60% of the assessment is attributed to the class tests and 40% to the assignments, which ensures that students cannot pass on the assignments alone. However, the disparity in average scores between the class tests and assignments (over the three year

period illustrated) requires further reflection to achieve more uniformity and hence better achieve the key module objectives.

Diagnostic verification of learning

In order to provide a benchmark for learning in this second engineering mathematics module, a diagnostic test was applied at the beginning and end, based directly on the relevant mathematical topic areas. Figure 2 shows the before and after results.

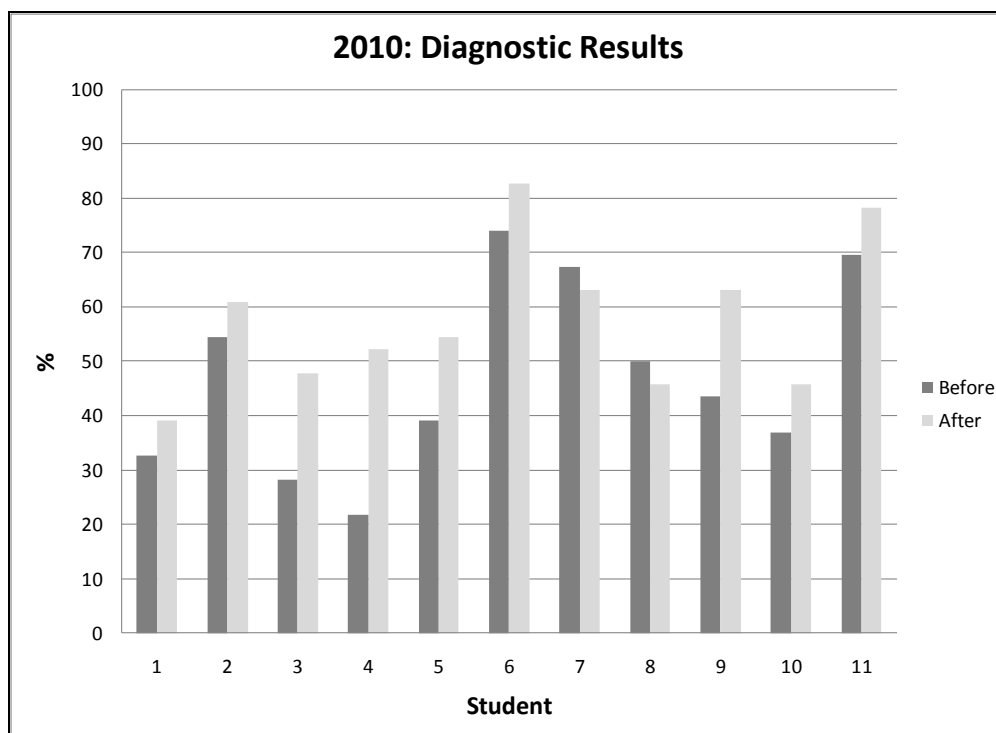


Figure 2. Results from 'before and after' diagnostic tests

Obviously, the same test was used on both occasions (without prior warning) and the results clearly show that the scores for all students bar two improved. On closer inspection with the results in figure 1, it can be seen that students 7 and 8 in 2010 had roughly similar results in the diagnostics and the class tests and so potentially 'cruised' through the CAA aspect of the module. The results are also interesting for students 3, 4 and 5 who made considerable improvements in the diagnostics, but performed poorly in the class tests.

Student Feedback

In line with the School's module evaluation process the three cohorts of students were asked to fill in a pro-forma questionnaire at the end of the new second-year engineering mathematics module. There were two sections on the questionnaire, the first asking for a score in relation to a particular statement regarding the module, to gauge overall satisfaction and identify areas of concern, and the second requiring the students to provide written comments to two open questions.

The first part of the questionnaire provided definitive proof that all students were satisfied with the module contents, the teaching methods, the assessment methods, the feedback and the lecturer's contributions to their learning. The results indicated a satisfaction level of over 90% for all aspects of the module. The second part of the questionnaire indicated that the students actually appreciated and even enjoyed the active and interactive teaching and learning methods employed. Their comments also provided further evidence on the efficacy,

engagement and attainment by indicating what was working well in the new module and what required revision.

CONCLUSIONS

It can be concluded that the active pedagogy employed in this new second-year mathematics module succeeded in motivating and engaging the students to the extent that they all passed the overall assessment process. Furthermore, the formative feedback from the students was very positive in relation to the CAL, CAA and the relevant simulation assignments that the module was structured around. Therefore, employing such an active and interactive learning environment engages the students in the learning process and the apparent advantages are:

- Students' understanding of basic mathematical concepts can be improved through CAL, CAA and relevant simulation assignments.
- It provides students with a flexible learning medium.
- It provides the opportunity to offer constant feedback to individual students.
- It provides instant feedback to the instructor enabling immediate and focused support for the students.
- Such two-way feedback helps develop and tailor the course.
- It provides an enjoyable and constructive learning environment which fosters a more positive attitude towards learning mathematics.

Some disadvantages to this approach are:

- The continual assessment regime employed requires more work for the lecturer.
- In-class active and collaborative activities require a bigger commitment from the lecturer.
- The logistics of setting up CAL and CAA requires a particular IT infrastructure and significant input from the lecturer.
- Workspaces are required with loose seating and computing facilities.

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TEACHER AND STUDENT INTENTION AND COMMITMENT IN A CDIO CURRICULUM

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ABSTRACT

The purpose of this paper is to highlight and discuss the impact of culture as a powerful outline for how to think, feel and act. Norms and routine acts are taken for granted and guide individuals as well as the organisation. In 1999 Linköping University started a collaboration between MIT, Chalmers and KTH with the aim of developing engineering education. This was the start of the CDIO initiative. In 2002 the first cohort of students in the study program of Applied Physics and Electrical Engineering (Y-program) entered into a program designed to meet the requirements of a CDIO syllabus.

In this study recurring interviews with ten Y-students between 2002 and 2007 and a focus group interview in 2010 with lecturers in the Y-program are used to discuss the following questions in relation to a selection of program targets:

- Students entering a study program have some expectations of what studying is and what the study environment will demand from and offer them. How do they express this during their period of studying?
- How do teachers express their expectations of the students and of themselves as teachers?
- Within the context of a specific study program, the Y-program, is there an alignment or a dissonance between the approaches to learning and studying expressed by the students and the approaches to teaching and learning, as expressed by the teachers?

Our results indicate that despite the curricular changes made between 2002-2010, both students and academic staff experience that the changes made, i.e. CDIO project courses, are joyful and useful but that these are not integrated into the “real courses” or regarded as “true teaching”. The norm of how to design and carry out the basic structure is strong and in the discussion we argue that this might be upheld by values in society, of Engineering as a solid male/masculine culture, where females find difficulties in adjusting, or changing the culture and therefore take on different paths or exit and leave the programme.

KEYWORDS

Approaches to learning; approaches to teaching; study culture; expectations; socialisation. Intentions.

BACKGROUND

In 1999 Linköping University started a collaboration between MIT, Chalmers and KTH with the aim of developing engineering education. This was the start of the CDIO initiative. In 2002 the first cohort of students in the study program of Applied Physics and Electrical Engineering (Y-program) entered into a program designed to meet the requirements of a CDIO syllabus. A CDIO project course was introduced the first semester and an elaborated

project course delivered in year three and a build-design course in year four. In a longitudinal study four cohorts of students, starting in 1998, 1999, 2000 and 2002 have been monitored on a regular basis throughout their studies, in order to see what their expectations were when they started, their experiences of their studies and their reflections on their studies after graduation, in relation to work and employment [1]. This study had a focus on student experiences in relation to the intentions in the curriculum and the CDIO syllabus. In 2007 the study was completed, but we are still working with the material, especially the longitudinal interview material. In 2007 the new degree structure of Bologna was implemented in Swedish higher education. This required teaching staff and administration to redesign course syllabuses and program documents with a focus on learning outcomes [2]. From 2007 there has been a growing interest in pedagogical issues among faculty and students, and the alignment between intended learning outcomes and examination has been highlighted with a focus on the meaning of “teaching” in relation to student learning. In 2010 a focus group was set up with academic staff who at the time were teaching in the Y-program. The aim was to have the teachers to talk about what “teaching” meant to them and have them express their experiences of being teachers in the Y-program. They all had long experience of teaching in the Y-program as well as in other study programmes.

In this paper we combine these data, longitudinal interviews with ten students who enrolled in the Y-program in 2002 and the focus group interview with senior academic staff in 2010 who had experience of the implementation of the CDIO syllabus as well as of the Bologna reform.

THE PURPOSE OF THE PAPER AND RESEARCH QUESTIONS

The purpose of this paper is to highlight and discuss the impact of culture as a powerful outline for how to think, feel and act as well as a web of conceptions and ideals [3] Norms and routine acts are taken for granted and guide individuals as well as the organisation and thereby save energy and facilitate interaction and communication, as people “understand” each other without having to make things explicit and without arguments. Culture is enacted through processes of normalization and subjectification [4], processes where individuals create themselves as distinct kinds of subjects through self-perception *and* signals from significant others. People within an organisation are encouraged to define themselves as the kind of people who are suited for the organisation and “chosen” for this kind of tasks. This definition produces a standard to which subjects commit themselves [3].

The Swedish government has commissioned the “Teknikdelegationen” (The Delegation of Swedish Engineering) to map all initiatives aiming at increasing the interest in science and technology among children and young adults, with a focus on females. The purpose is to prevent a gap between supply and demand among engineers when many baby boomers retire [5]. In 2009 a report was published [6] where the Swedish engineering educations in Electrical engineering and Mechanical engineering were monitored by the Association of Swedish Engineering Industries. One conclusion in the report is that there are different opinions on what the “core content” of a Master of Science in Engineering should be. The employers focus on “solid and traditional engineering knowledge and competences” while academics focus more on disciplinary and generic competences. One conclusion is that teaching and content should be more aligned with work-life demands, i.e. more project based and work based learning activities and it should be easier for students and employers to understand what a degree means and what can be expected from a graduate student.

Despite curricular changes, marketing efforts and branding, there are difficulties in attracting and keeping engineering students, especially females, and the questions we ask in this paper are related to the study culture of the program.

- Students entering a study program have some expectations of what studying is and what the study environment will demand from and offer them. How do they express this during their period of studying?

- How do teachers express their expectations of the students and of themselves as teachers?
- Within the context of a specific study program, the Y-program, is there an alignment or a dissonance between the approaches to learning and studying expressed by the students and the approaches to teaching and learning, as expressed by the teachers?

METHOD

For the purpose of this paper we are using two different data sets. One set is the student interviews collected within a large, longitudinal study [1]. The other set is a focus group interview with 5 academic staff [8]. The student interviews cover a period of six years, 2002-2007, while the focus group interview was made in June 2010. Between 2002 and 2010 there has been curricular as well as organisational changes in the Y-program and the intention was to see if these changes also had changed the way students and staff experienced and talked about the quality of the program, about teaching and learning and the identity of the program.

Both sets of data have been analysed in relation to four selected qualitative targets for engineering education [7] (our own translation into English).

- 1) Knowledge and understanding: show a broad knowledge within the chosen field of technology, including knowledge in science and mathematics, as well as considerably deepened knowledge within specific fields.
- 2) Skills and competencies: show an ability to identify, formulate and manage complex problems in a critical, independent and creative way with a holistic perspective and be able to participate in research- and development work and thereby contribute to the development of knowledge.
- 3) Skills and competencies: show an ability to work in team and collaborate in diverse groups.
- 4) Judgements and approach: show an ability to make judgements based on relevant scientific, social and ethical considerations and show awareness of ethical aspects in research- and development activities.

Student interviews

In this paper recurring interviews with ten students are used [1]. Five male and five female students who enrolled in the Y-program 2002 were interviewed, twice during the first year and after that once a year until graduation, or until they left the program. The interviews were conducted between 2002-2007. For the purpose of this paper the interviews have been read through and reanalysed with a focus on the students expectations of the study environment and of their achievement when they started; their approaches to learning and studying and their experiences of the study environment during their studies.

There were in all 26 interviews with the male students and 15 with the female students. Three of the five female students dropped out or made longer periods of study leave in combination with work and they were not able to participate in the study to the same degree as the male students.

The analysis of the student interviews generated five themes:

- Approaches to studying and studies
- Experiences of course/program design
- Study strategies
- Approaches to teachers and teaching
- Identification with the Y-program

Focus group interview

In the beginning of 2010 the Chairman of the Program Board for Electrical Engineering, Physics and Mathematics was contacted and informed about the project and asked to recommend a number of teachers that would fit the criteria of teaching in the Y-program at present and with some previous experience of teaching in higher education. He was asked to suggest male as well as female teachers to be interviewed.

Ten teachers were addressed via an e-mail in which the project was described and they were asked to sign up for a participation in the study. Five persons accepted the invitation, one female and four male teachers. They all have some experience of the CDIO syllabus, but they also teach in other engineering programmes where the CDIO syllabus is not so evident.

The teachers received a “welcome-letter” where information about the study as well as practical information was given, for example time and place for the focus interview.

The study took place in June 2010 and was conducted at the Centre for Teaching and Learning at Campus and lasted for about two hours. The entire interview was recorded and later on transcribed entirely.

The method, focus group interview [8], was chosen since it would admit the teachers to interact as a group while describing their experiences of teaching at the Y-program.

In the beginning of the interview the teachers were informed about the aim of the study and also about the method to be used. The question in focus was : How do you perceive teaching in higher education according to your experiences and what is your approach to student learning and teaching in a Master of Science in engineering at LiU, namely the Y-programme.

During the interview questions concerning “how we do it” tended to be in focus rather than discussions about what teaching “is or might be”, in a more philosophical sense. Throughout the interview the teachers made references to the targets for engineering education, although without explicit wordings. Instead they talked about what competences a Master of Science in engineering should develop during the educational process. The main focus was in what way their teaching could contribute to this.

The transcribed interview was read through several times. The analysis generated four themes, with a focus on the competences related to the emergence of a graduate engineer.

- a solid ground in mathematics, natural sciences and technology
- the problem solver
- the communicator
- the scientist; with characteristics such as autonomy, critical thinking and creativity

The data was analysed based on the group as a whole. The results that will be presented in the next section of this paper will mainly be illustrated by an assortment of quotations chosen with the aim of illuminating the variation among the experiences expressed by the teachers in the group

THEORETICAL CONSIDERATIONS – PREVIOUS RESEARCH

Key concepts used in this paper are *intention* and *commitment*. The concept of intention originates in the works of Husserl, who was a mathematician who became a philosopher whose work is about how to understand how people make sense and meaning of the world. For Husserl intentionality means that human thoughts and actions always are directed towards something, an “object”, we are always part of the world, even as researchers! Within this broad, epistemological framework we give meaning to the concept of *culture* [3] that derives from organisational studies, indicating that there are norms and routine acts that are taken for granted and that these guide individuals as well as the organisation. It is when you

are a newcomer you sense the culture, in what is defined as “normal” or “deviant”. People who are within a culture think about themselves as “we” in relation to “the others” and they tend to commit themselves to the culture and identify with its values. Another concept used is the concept of *subjectivity* [4], a process where individuals create themselves as the kind of people who fit in (or not), in response to their self perceptions and the perception of significant others. This culture is enacted in the design of the study program and the ways of thinking and practicing the subjects taught [9, 10; 11; 12]. Ulrichsen [13] argue that the structure of a study program, the modes of teaching that are applied and the teachers’ expectations and experiences all have implications for the students. In a study he showed the contradictions and ambiguities of both students and teachers in a study program in science. The taken for granted, unspoken anticipations about what studying is and the meaning of studying contributed to teachers’ frustrations of uncommitted students as well as to the students opting or dropping out. The concept “the implied student” indicates that there is a structure, inherent in the way the study program is designed and carried through, but it is also a structure of action in the sense that students and teachers “do” the study in particular ways, in their actions. Knewstubb and Bond [14] introduce the concept “communicative alignment” to describe similarities and differences between the teacher’s intentions and the way the students perceive the lecturer’s intentions.

” If beliefs about knowledge, teaching, learning and the subject were treated as part of the interpretive context of teaching-learning communication, it might be possible to develop models that integrate the conceptual and communicative elements vital to higher education” [14].

Becoming a Y-student, and being a teacher in that programme, means complying with, or relating to, a set of cultural and disciplinary cultures [13] but different persons have different possibilities and restraints in their way to “perform” their positions as students and/or teachers, depending on gender, cultural background and professional goals as well as on the organisational culture. Women, in a male/masculine culture, have to perform their positions in a different way than their male peers [15]

Key concepts in this paper are *approaches to teaching and learning* and in elaborating on the intentions and commitment of students and academic staff we are using the concept of “Quality of learning achieved” [9] where the concept of “*student learning*” has been broadened, from a main focus on conceptual understanding to the covering of additional skills and ways of thinking, both academic and professional, referred to as WTPs (ways of thinking and practising in the subject). Within a specific subject area, i.e. engineering, crucial topics or concepts are identified and the difficulties identified by students and teachers are conceptualised as troublesome knowledge [16] threshold concepts [17] and delayed understanding [18]. The ways *teaching* is carried out depend on the collective pedagogical WTPs of teachers providing it, but also by institutional priorities, the teaching ethos of the department and the outside influences coming from the academic community as well as from validating bodies and student expectations [9].

In order to understand why some people adjust and comply to the norms, while others try to influence, change and develop it and some people exit and leave we use the concepts of *dissonance and friction* [19; 20 ; 21; 22], indicating that people whose expectations and values are *not* aligned with those prevailing tend to experience some kind of dissonance or friction. These can contribute to development and change, or they can contribute to compliance and/or exit and withdrawal. In line with this there is the assumption that the way people act converge with their intentions, their goals and motives for wanting to stay. According to this, within a specific culture, people can stay and adapt to the culture either as a necessary evil, trying to survive, or because they identify with the culture and want to be a part of it.

RESULTS

The results will be presented in three parts. First the results of the student interviews and after that the results from the focus group interview and finally the result when these are integrated and related to theoretical frame works.

Student interviews

The five male students all completed their studies, although within a time span of about two years. One student became a PhD student and one worked as teaching assistant at the end of his studies. Although their study motivation failed at times they kept a stiff upper lip and finalized their grade. The five females and their responses as well as their study trajectory differed from the males. Three of them described themselves and their studies as a “disaster”. They tried to compensate periods of lack of study motivation with engagement in other extra curricular activities and/or social activities. This in turn contributed to delays in their study pace and in 2007 they had not yet graduated. The female students commented on the harsh culture, feelings of military camp and experiences of hostile lecturers. They also commented on the benefits of being different. As females they were noticed, their names were remembered and they felt free to ask “silly questions” in class and in private to lecturers. Both male and female students express themselves in the themes and citations are chosen to show the variation of expressions. Where there are obvious gender differences this is commented in the text otherwise “students” indicate male as well as female students.

Approaches to studying and studies

The students approaches to engineering studies are expressed as a solid interest in the subjects, mathematics, physics and technology, and an aptitude for that kind of studying.

“I believe I have a natural aptitude for this kind of studies. I have always managed very well at school...and it is fun to study...fun with mathematics and physics”

They emphasise that their interest is not primarily to strive for a career as an engineer, as they have very vague ideas of what this means. Their interest is in studying, being students, learning and achieving.

“The attraction was not a career (as engineer) but the challenge..”

As the Y-program is considered to be a tough program, the challenge of managing this as well as the prestige and pride to be part of this community, are driving forces.

“The Y-program is quite famous and to graduate from that has some prestige”

This makes it quite hard for the female students who “failed” during the first years and therefore lost their self confidence for a while and either compensated this by engaging in extra curricular activities or dropped out.

“At times it has felt like a waste of time and I really have been a failure and my self confidence is low...but I really want to study in this program”

The students approaches to studying were also expressed as based on some inherent, personal characteristics, i.e. being competitive, achievement oriented, ambitious and talented. They did not work too hard in secondary school to keep up a reputation of being among the best.

The approaches to studies and studying are based on the students general interest in studying and their solid interests in subjects like mathematics, physics and technology. They seldom talk about engineering as a profession or about engineering competencies and some of the students even express a fear or disdain of work life, in relation to studying.

“...to be honest, it frightens me more to get out on the job-market, than it motivates me”

Experiences of course/program design

During the first years the students describe the design of the program as fixed, with compulsory classes that has to be attended to and exams to be passed in order for them to be able to be eligible for the last years when there is more freedom of choice.

“ They (faculty) told us from the start we know what we teach you and everything is planned in detail....but it has been very one-sided, a lot of maths and stuff”

“It is very well thought through, how we go through the foundations, step by step...but I guess I will not use all this knowledge...with some of it, you have no idea what the meaning is”

The opinions of this design is ambiguous. The program structure is talked about as “a necessary evil”, something you have to endure, manage and survive and if you do you are among the smart and successful students who can later choose courses out of interest. The price they pay is a loss of the interest and passion for the subjects that some students had from the start, and a disappointment when they find themselves adapt to a study behaviour where they just do what they are expected to do without thinking and/or reflecting. This was most outspoken among the female students. After the first two years they justified the design which they now realised provided them with the knowledge and skills necessary for their elected profile courses.

“Now (year 3) we are taking more applied courses and that is what interests me, things I enjoy like space research, mathematics, electronics and the like...you can not change the program and make it easier because this means lowering the quality”.

“The courses are more and more related to reality...you get a sense that they have something to do with what you are going to work with in the future”.

Some students had tried to influence the overall structure, but their efforts were met with arguments that “this has always been done like this”.

During the first semester and in year three and four they had a CDIO project course. All students said that these courses were interesting and fun although very time consuming. They mentioned that it was in these courses they learned to collaborate, work in teams, leadership, communication and to apply their knowledge in a real, complex situation.

“It was really fun! So different from everything else we have been doing, all the theoretical stuff...now we could *do* something and apply our knowledge”.

Despite that, the experience that they learned a lot and put a lot of effort in their work, they did not consider this to be a “real course”. It was a benefit, a project that “stole” precious time from “the real courses”. They also talked about the CDIO courses as “breaks” from mathematics and other hard stuff. Project work was associated with pleasure and within their own control and therefore did not count as a “real course” or “true teaching”.

“It was a nice break because I am so tired of studying for examinations...and finally you can apply what you have been studying, ..it is so much more fun”.

“It was a break from the ordinary studying, to build these robots... it is a bit more like engineering”.

One suggestion the students had was that the whole program should be more project based, but they commented that it would be impossible as they would not be able to cram in all the necessary course content.

Study strategies

All students had the *intention* to manage the program and graduate, but they used different study strategies to achieve their goals and they had different experiences about the price they were willing to pay to manage. Both male and female students preferred to study for the examinations on their own, in solitude.

“ I need time to calculate, think over and think through things before I discuss with others...I do not want to have my line of thought disturbed before I am

ready”.

Female students preferred to study with friends to a higher degree than male students. The study strategy during the first two years was to attend all scheduled activities, to plan everything and discipline themselves. Female students commented that they also wanted to have a life outside the university, and that they at times gave priority to friends and family. The price they paid was that they lacked behind, could not keep up the pace. To attend lectures, go home and drill all stuff into their heads was the way they worked, in order to understand what they were reading in their traditional courses. They have a different approach to their project courses where they work in groups and learn to plan and manage their time and to collaborate. They also have another approach to the way they study their elective courses (year 3-5), when they take control over their ambitions, study pace and ways of studying. One female student, who has taken control through designing her own study path and eventually was doing very well, commented

“ I do not think I have become smarter over the years, it is just that I never had time to reflect on anything before”.

Approaches to teachers and teaching

The students do not talk about their “teachers”, they talk about *lecturers* who lecture in big halls for 100-200 students.

“You do not have much contact with lecturers and a bad lecturer makes you loose an interest in the course....a good lecturer can explain and talk so you can understand and a bad lecturer does not engage in the lecture and does not care who he is lecturing for”.

In smaller classes they have “lesson leaders” and they elaborate on the lectures and the students can ask questions and get supervision. A good “lesson leader” is helpful and a good listener.

“The lecturer go through the stuff, rattles off what is in the book, and demonstrates it. If you do not understand, it is the role of the lesson leaders to help”

Then they have labs where senior students or PhD students assist and answer questions. A general opinion is that teaching staff know their subjects but that their attitude to the students and teaching skills vary and the students are more satisfied in year 3 and 4 than during the first two years. Male students are more impressed by the quality of teaching staff than female students.

“I think they are good..they know their stuff...they are quite tough and self-assure, a bit like Arnold Schwarzenegger”.

Female students comment more on the attitudes and the masculine setting and tough climate.

“ I have been very upset with some teaching staff...very hostile to females..you do not want to ask him questions because he makes you feel stupid..he is well known for this but he is good at his subject”

Both male and female students comment on the age of the teaching staff and appreciate younger persons.

“The feeling is that the older ones should need courses in pedagogy...maybe they just want to do research instead of teaching...it is as if they do not really have time for us”

The students appreciate teaching staff that they can talk to and understand and who are committed and helpful.

Identification with the Y-program

Being a student in the Y-program means that you acquire skills to solve problems and think analytically. As it also is considered to be a tough program, where the demands are high, graduating from the program gives a professional self confidence to those who have passed

and graduated. There is a gradual selection during the program, as one male student commented “you sort of get cast in the same mould”, while one female student expressed the feeling of identity as

“it is a bit like being in the military services...it is a very strong feeling that it is ‘we’ against ‘them’ and ‘we’ are the best!...I find a lack of reflection and thoughtfulness among these people...nobody talks about what we are doing with our knowledge”.

They describe the quality of the program as a formation of character, and in order to succeed you need a proper foundation, i.e. students who are “a bit special”, nerds, who like to keep to themselves, self-disciplined, ambitious, able to manage everything, have a passion for mathematics and are *very* smart. One female student comment on her own description by saying that “they really *are* very smart and can manage *anything*... a kind of superman”...but at the same time she claims that when you are part of this community you realise that they are “‘like everybody else’, young people who like to party and have their ups and downs”.

The students also reflect on this image in relation to their own characteristics and identities and come to the conclusion that this is what potential employers look for

“they say that the profiles really do not matter so much, it is the fact that you have graduated from the Y-program, that you are a Y-student that matters when it comes to employment”.

Focus group interview - Teaching in a Master of Science in engineering.

The teachers talked about the teaching they conduct in three different ways partly depending on the situation and the group of students they were teaching. An example of the first approach, where the role of the teacher was described in terms of transmitting knowledge to many students simultaneously, is illustrated by the following quotation

“You mediate lectures and knowledge in a strictly structured and digestible way to help the students collect information”

Another approach is illustrated in the following, now with the focus on motivating the students

“I don’t just stand there telling them things expecting them to listen and that’s it. What I’m trying to do is to make them enthusiastic, make them feel it’s fun. They are the ones who have the ability to learn, however not by me. Once you’ve got a person interested in something all other problems are solved”

A third way of talking about teaching illuminates the fact that learning and teaching can be conceived as a process of progression

“There is an enormous progression during the educational process, the way you treat the students, your attitude towards them.....from being a nanny to treating them as highly competent adults”

Among the teachers in the focus group there was one opinion that they all shared and that is what teaching “is not about”, related to the way it is conducted. What might be described as teaching activities is not always what they perceive as true teaching. As they lecture in front of a large group of students they do not teach in a true sense, they lecture and that is all. Thus they make a distinction between their role as lecturer and supervisor and illustrate in what way this can restrict them in their teaching efforts. They described true teaching as taking place when there is some kind of two-way interaction between the teacher and the student, for example during lessons, supervision or lab-work.

“When there is an interaction, a reciprocal relation where both parts get stimulated intellectually”

“When you are supervising and meet the student over a longer period of time and you can see a progression and you say to yourself: ‘Shit, he wouldn’t have managed to work this out one year ago!’. Being part of this makes you feel that you really are a teacher, you’re part of the process, so to speak ... you share the experience”

“When you really feel that you are a teacher is when you sit and talk with one or two students and try to explain things and all of a sudden you can see that they have understood something”

“When I give a lecture and stand there talking in front of 250 students, then there is no interaction, although I am a teacher in a formal sense”

The teachers talked about the CDIO syllabus as a supplement to the fixed design which they described as “traditional teaching”, i.e. with lectures followed by lessons and lab work and finally the individual written exam. At the same time they described the interaction between the teacher and the students during project work as outstanding in a qualitative sense. Now and then the teachers commented that CDIO has changed things

“There have been many changes on the Y programme, not because of Bologna but by introducing CDIO-courses”

“Maybe the culture is changing as an effect of CDIO”

The female teacher mentioned that there is a problem worth mentioning and that is that there are so few women attending the Y-programme. She described it like this

“There are no role-models for the girls. When you discover that all the teachers are men and that the rest of the students are men you realize from the very beginning that you won't have a chance here. And then the smart girls will choose another programme”

One of the male teachers made a comment on this

“I don't think there would be a different culture on the program if there were more girls there”

While listening to her male colleagues describing traditional teaching on the Y-program the female teacher now and then asked them

“What will the teaching that you conduct lead to? What will the students become? “

The first answer, which came up immediately, was

“They will become problem solvers”

One of the teachers expressed his intentions related to the modes of teaching that he has adopted in relation to a new generation of student:

“Fifteen years ago they (the students) didn't ask questions like ‘Why do we have to learn this?’. They trusted the teacher and if he said that this is important they figured it to be important. So I have changed my way of teaching today I have to motivate them”

Focus group interview - To become a Master of Science in Engineering

During the interview topics concerning the students were in focus to a large extent; who they are and what they are to become, i.e. Masters of Science in engineering. The following presentation is built on four themes that were emerging during the analysis of the data from the focus group interview.

A solid ground

All teachers stressed the importance of helping the students to develop a solid knowledge base in mathematics. They also shared the opinion that this should be a main task in the early stages of the study programme. When they discussed in what way teaching could contribute to this effort there were two different approaches emerging. One of the teachers described the way in which the teacher's knowledge in the subject can be transmitted to a large group of students simultaneously.

“By lecturing, the teacher's experience of the subject and its structure is transmitted to the students. It constitutes the fastest way to gain knowledge in the subject area at hand. It's a way to rationally and in a short period of time become acquainted with a subject and gain crucial knowledge. The role of the teacher is to make the learning

process fast and rational”

Another teacher described student learning as a process where knowledge is developed by the student herself and where the teacher’s role is to facilitate understanding.

“I want the students to understand what they are doing, not just gaining some knowledge on the surface, memorizing without understanding. The thing is that mathematics is what I am up to and when it comes to mathematics understanding is fundamental. I would rather prefer more limited knowledge within a field as long as the students really understand what they are doing”

The problem solver

During the interview the teachers often talked about the students in terms of “engineers to become”. They stressed that these students are to become problem solvers who are able to identify, structure and solve any problems that they will face as engineers.

When it comes to how these competences might be developed there were different opinions among the teachers in the focus group. Some of them described their teaching as a shaping process where the students step by step develop problem-solving competences.

“You can see it during the lessons where you as a teacher can make a good example to the students by initially writing explicit and well structured solutions on the white board while, after some time, just giving them an outline with the details implicitly assumed. The balance between these two strategies varies according to how far the students have come in their studies”

Some teachers stressed the importance of letting the students implement their knowledge even at an early stage by working in a more hands-on way and thereby develop their problem solving abilities as well. One example of this is an utterance from the female teacher when she stressed the importance of letting the students themselves find out what kind of knowledge they need to solve certain problems

“CDIO has refreshed the program a lot and made it more vital. You get a chance to apply your knowledge in a way that was not so common earlier I conceive these CDIO-courses as very positive since you can bring something from the research area into teaching once the students ask for it as they themselves have discovered the need for this kind of knowledge to be able to solve their problems”

The communicator

Those of the teachers who work at the early stages of the program described this as a challenge, since the students on the Y-programme constitute a rather silent group. On the other hand most of the communication between the students and the teachers take place via lab-reports and written exams. It is to a large extent up to the teachers and the students to decide about the amount of interaction and the kind of interaction. Later on in the program there are more opportunities to meet and interact in smaller groups as well for the students as for the teachers, for example during supervision sessions or project work.

Many times during the interview the teachers stressed the importance of skilled interpersonal communication for the Engineers to become. They described it as a relief that there are project courses integrated into the program (CDIO-courses) since these courses build on interaction and communication and thus should contribute to the development of related skills and competences. The following citations describe the dilemmas that the teachers experienced

“The students on the Y-programme are quiet. They have always been and will always be like that”

“I think it is quite hard with a group of Y-students, to make them ask questions. They are rather quiet. However, you can see that they sit there thinking about something and then you’ve come a bit further in your teaching”

“They will have to work together in groups, discuss and manage the task. They will have to interact (on CDIO-courses). That’s one of the reasons why these courses

have become so popular, I believe”

“I don’t think it has changed our way of teaching but with *supplements* like these the students will develop new competences like planning, organizing, writing and presenting”

The scientist

The teachers described many students as autonomous, with creative and critical thinking abilities already at an early stage of their studies. However, these talented students are often rather quiet and prefer to work on their own to a large extent. The teachers in the study asserted, with a smile on their face, that these students manage very well without taking part in any teaching activities.

“Students on the Y-programme who sit and work by themselves during the first years at university are potentially interesting people to recruit for PhD-studies. They are extremely intelligent, competent and independent students. However, you have to make them start talking and fix that part, but when it comes to that we have been successful with many students”

When it comes to the students who are not as gifted as the ones described above the interviewed teachers stressed how important it is to let also these students find out the questions by themselves and search for answers. In that way they will be able to develop skills as critical thinking and autonomy. During the first years of studying it is very much up to the student to ask questions and initiate interaction with as well other students as the teachers. Later on, in the project courses, these activities are built in already in the design

“On the CDIO-courses the students are allowed to initiate questions and actively search for knowledge. I am convinced that this approach supports their later ex-job”

“The students will probably gain a broader view on knowledge within the field through the CDIO-courses. There is not always one appropriate answer to a certain question”

One way to develop the skills of a scientist is to become acquainted with research work. This is something that the teachers in the study agree upon. However, they find it hard to integrate research into the teaching process at an early stage. One of them said like this

“On the basic courses in mathematics it happens that the students ask me: ‘How do you do research in mathematics?’ and that’s not easy to explain to them at that stage”

Later on it is easier

“I teach courses in the fourth year and I think it’s easy to relate teaching to research, especially in the CDIO-courses. There you can bring the very latest from research into the courses”

At the end of the focus group interview one of the teachers concluded:

“It is fascinating that we agree to a large extent when we discuss teaching like this. There is a culture and I don’t know to what extent you could say it is local. But, on the other hand, we spend our time here with colleagues who have also studied here, been fostered in the same culture and now act in the same way as *their* teachers once did”.

Alignment or dissonance between approaches to teaching and learning in relation to culture and program targets

Following the arguments of Alvesson [3] the results of these interviews indicate that the culture of the Y-program is enacted and strengthened through processes of normalization and subjectification, where students *and* academic staff create themselves as distinct kinds of subjects through self-perception and feedback from significant others. The “traditional design” of the program, meaning that the first two years should both lay a foundation of basic knowledge and skills and shape the students’ characters into disciplined, hard working and well performing students, is enacted in the design of the program as well as in the modes of

teaching and strategies for studying. Acting in this way, complying to the norms, is regarded as “normal”, although female students, as well as the only female teacher, comment on the different options there are for males and females to live up to, and perform, these standards [13] and Söndergaard [15] shows that women, in a male/masculine culture, have to perform their positions in a *different* way than their male peers. An example of this is that it is female students and the female teacher who argue that there is no discussions or reflections in the programme on the *meaning* of the studies and the *consequences* of the generated knowledge, which they lack. In the focus group interview the female teacher continuously asked her male colleagues about the meaning and relevance of their teaching, but the male teachers brought it back to the teaching of the courses. Another example is the female students who described the culture as very masculine and military like.

The teachers interviewed have themselves been “formed” as undergraduate students, PhD students and junior lecturer and they belong to those who have succeeded and made an academic career, not an engineering career, and the students comment that due to the tough and demanding studies they find themselves entangled in a “small world” of people of the same way of thinking, people who are prepared to work hard and make sacrifices in order to show that they are suited for the program. Those students who have doubts, or fail, or have ideas about other ways of running the program but stay, develop strategies where they gain more time and more personal control of their work situation. Ulrichsen [13] points out that the concept “the implied student” indicates that there is a structure, inherent in the way the study program is designed and carried through, but is it also a structure of action in the sense that students and teachers “do” the study in particular ways, in their actions.

Despite the fact that the reforms in the Y-program were aiming at attracting and keeping students, and there has been curricular reforms and a general change in attitudes, the underlying norms seem to persist, i.e. the basic structure and modes of teaching. Evidence for this is the alignment between the way the teachers talk about their teaching and the students’ learning in 2010 and the way the students talk about their learning and the teachers teaching between 2002-2007.

In this culture the first two years is also regarded as a period when students classify themselves and are classified by the program, based on the required standards for an Y-student. This kind of classification contributes to a sense of belongingness, of strengthening the bonds between those who are suited for this kind of studies and a justification of the design and the modes of teaching that these competent lecturers practice. The bond is further strengthened after the first two years, when the students are more free to elect courses out of interest and to take control over their work, and when the teachers meet with smaller groups of students who have elected their courses. At this point they meet in a kind of master-apprentice learning relationship.

There is an alignment between the approaches to teaching and learning and the program target about *knowledge and understanding*. There is also an alignment in the norms, how this is performed, through a fixed structure, cramming of content, reading for exams and a tight schedule the first two, basic years. Both teachers and student deliver intended results. For those students who are successful the reward is more committed teachers and better opportunities to choose courses out of interest and gain control of their work and for the teachers more committed students and a more professional relation.

There is some ambiguity in relation to the program target about skills and competence to work in teams and to collaborate in divers groups. As many students (but not all) and the teachers argue that this is on one hand what future employers require and it is fun and interesting to collaborate, construct and build and work in teams, but on the other hand this is time consuming, stealing time from “the real courses and the true teaching”. The learning of skills and competence is related to the project courses, and these are not defined as “real courses”, they are supplements to these.

There is little alignment in the approaches to teaching and learning and the program targets about skills and competence as critical thinking, solving complex problems and to show an ability to make professional judgements. The teachers argue that these skills and competences will emerge, as a result of graduating from the program, without teaching or examination, as these targets are difficult to assess. And the students argue that they learn these skills and competence in situations that are not related to “real courses” or “true teaching”. They learn this in project work, thesis work, work life experiences and social activities in the programme and in private life.

To conclude, the teachers argue that during the first two years of the programme they are not teachers, they are lecturers who deliver content in relation to pre set learning outcomes and a fixed structure. It is not until year three or four, when they supervise and lecture smaller groups of students, in their own field of research, that they *are teachers*. They “set eyes” on the students and get a more personalised relation to the students. The students have the same experiences. The culture of the program, the program design and the ways of teaching and practicing that are performed contribute to this successful story. But every success story also has a darker side, where those who have not managed, or wanted to adjust to the norms and rituals, have left the program, or suffered from failures and losing their self confidence and passion for the subjects. If this is desirable or a failure for the institution is a question of values. What is the sense of the programme and what kind of engineers do we want to graduate?

| DISCUSSION

The purpose of this paper was to highlight and discuss the impact of culture as a powerful outline for how to think, feel and act in a study programme in Engineering, the Y-programme, that has implemented a CDIO curriculum and since 1999 made curricular changes to meet the requirements of a CDIO syllabus. The results indicate that *despite* these changes made, both students and academic staff have the experience that there are powerful processes of normalisation operating, meaning that the basic design and structure of the program, as well as ways of thinking and practicing the subjects, are so taken for granted that changes within the program can only be done *within* these structures, the structures are not possible to change. This can be related to the proposals from “society” where the lack of interest among young people (read females) to study science and engineering is highlighted as a big problem. There is also a concern about the gap between the intentions and commitment of the academic world and the world of business, where the latter worry about graduates who do not hold enough “engineering competence”.

It is difficult, and challenging, to try to understand what this is all about. Our results indicate that the CDIO syllabus, especially project work, is considered to be useful and joyful experiences by students as well as teachers, and that it is in these settings that students reach several of the program targets. However these experiences are not considered to be “real courses” in the programme.

One way of understanding this is that these paradoxes are not only the results of what happens in this programme, it can be the result of the values in society. In Sweden there is now a debate about education and educational quality, enacted as a reaction to the last 20-30 years of educational reform, focussing student centred learning, group work and a study environment based on lust and joy. The reaction calls for “back to basics”, discipline, hard work and solid knowledge bases. The Y-program has maintained these values and virtues during these years, and thus been scorned and questioned for not adapting to the mainstream pedagogical strands. Has this been made possible because engineering is one of the last male/masculine dominated cultures in Higher Education? To change this culture, and welcome a diversity of students, and not only make supplemental changes that neither

teachers nor students incorporate as “real courses” or “true teaching”, might challenge the idea of what “quality” stands for. Is it desirable that the quality of an engineering education for the 21st century primarily is regarded a school for the forming of characters, like boarding schools and/or military services, or as a springboard for innovation, creativity, sustainability and the forming of democratic citizens who can communicate, negotiate and collaborate in a diverse, global society.

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DOES AN ASSOCIATION BETWEEN STUDENT EVALUATIONS OF RELATED CDIO COURSES EXIST?

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ABSTRACT

This paper discusses possible uses of student course evaluations on a pair of courses developed to comply with the CDIO concept. It is seen that both similarities and differences in the evaluations can be found. These can in part be used to assess if the CDIO concept has been implemented as it was intended and possible adjustments can be suggested.

The data consist of 33 observations with full information on 8 general course evaluation questions on each of the two courses. The data has been collected over three years (2008, 2009, and 2010). This makes it necessary to consider methods which are able to handle possible differences between years.

We illustrate different ways to analyse the associations between the two courses by utilizing such data. Inferences about the mean differences between the courses are performed using analysis of variance techniques. In this context they may be considered as generalisations of the paired t-test. The generalisation to an analysis of variance makes it possible to handle differences between years. Inferences about the correlation structure of the data are performed using so-called canonical correlation analyses. A possible difference between years of the evaluations makes it necessary to consider adjusting the data for the year effect.

We find that one course generally is evaluated as more satisfactory than the other on five of the questions. Also we find a very strong effect of year, indicating the need to remove the year effect before proceeding with the canonical correlation analysis. The canonical correlation analysis is only significant at a 10% level of significance for these data and resulting associations must therefore be interpreted with caution. The interpretation results in a combination of evaluation questions for one course which correlate well with another combination of evaluation questions for the other course.

KEYWORDS

Associations, student evaluations, related CDIO courses, paired t-test, analysis of variance, canonical correlations

INTRODUCTION

Universities all over the world discuss ways to improve the quality of the teaching and learning processes. As stressed by the CDIO homepage: [1] "The CDIO initiative is an innovative educational framework for producing the next generation of engineers. The framework provides students with an education stressing engineering fundamentals set in

the context of Conceiving — Designing — Implementing — Operating real-world systems and products. Throughout the world, CDIO initiative collaborators have adopted CDIO as the framework of their curricular planning and outcome-based assessment.”

Teacher evaluations and overall course quality evaluations are widely used in higher education. Students submit their feedback about the teacher and the course anonymously during the course or at the end of the course. Results are usually employed either directly by the teacher(s) or indirectly by management to improve courses for future students and to improve instructor effectiveness. Many researchers have stated that student rating is the most valid and practical source of data on teaching and course effectiveness [2] (McKeachie, 1997). Therefore, research on student evaluations is critical to make improvements in course construction and teaching methods.

Many authors have considered different ways of analysing, interpreting and utilizing evaluation data. Some are on relationships in the questionnaire itself. In [3], Cohen considers the analysis of data from 67 multisection courses and found an association between overall instructor ratings and student achievement. This study was later refined by Feldman [4]. In [5], Althouse et al. consider the relationship between ratings of basic science courses and the “overall evaluation” of the courses. Guest et al. [6] compare the survey responses with the actual examination performance of the student. In [7], Ersbøll considers grouping of the different questions by factor analysis and examining consistency between different years. He also investigates which questions are most related to the grade achieved by the student. Finally, Sliusarenko and Ersbøll [8] consider the relationships between general questions related to the course and general questions related to the instructor.

The CDIO concept was formally introduced in the professional bachelor degree education at DTU in 2008. This paper analyses routine course evaluations performed by students in the computer science related professional bachelor degree educations at DTU. Specifically, a pair of related courses is considered, namely: “Introductory Programming” (course no. 02312) and “Development Methods for IT-Systems” (course no. 02313). Both courses include lectures and lab work. However, the first is slightly more oriented towards traditional lectures while the second is slightly more oriented towards project work in groups. Together the pair of courses cover the CDIO concept and it is the intention that the courses be taken in parallel during the same semester. It is therefore of interest to analyse the evaluations of the courses together utilizing that (some of) the students have evaluated both courses. Here we consider ways of detecting differences between the course evaluations and other possible associations between the evaluations of the two courses.

DATA

The student course evaluation questionnaire used at DTU is standardised across the university. The actual evaluation is performed online through CampusNet (the university intranet) a week before the final week of the course. The questionnaire is split in three parts: form A which considers course related questions, form B which considers teacher related questions, and finally form C which is a free format qualitative feed-back form considering three cases: “What went well?”, “What did not go so well?”, and “Suggestions for changes”. In the present analysis we will only consider form A.

To conduct the analysis we collected the evaluation results from two bachelor level courses from the department of Informatics and Mathematical Modelling at DTU: “Introductory Programming” and “Development methods for IT-Systems” which correspond to 10 ECTS points and 5 ECTS points respectively. Together the pair of courses is considered to fulfil the CDIO concept. Furthermore, it is recommended that students follow the “Introductory Programming” course at the same time as the “Development methods for IT-Systems”

course. Therefore some students will have filled in evaluation forms for both courses. The course characteristics (taken from [9] and [10]) are given in Table 1.

Table 1
Course characteristics

Course name	Introductory Programming (02312)	Development methods for IT-Systems (02313)
Points(ECTS)	10	5
Course type	bachelor	bachelor
Scope and form	Lecture, exercises and a programming project	Lectures and lab work
Duration of Course	13 weeks + 3 weeks	13 weeks
Type of assessment	Oral examination and reports	Oral examination and reports
General course objectives	The goal of the course is to make the student able to use the basic concepts and techniques in an imperative- and object oriented programming language. The course will use a programming language that is used in industries (JAVA). The main purpose of the course is to make the student able to design, implement and test smaller programs	The purpose of the course is to train an engineering approach to developing software systems in small project groups
Learning objectives:	<ul style="list-style-type: none"> • Understand the different number representations • Use loops and branching. • Understand classes and the anatomy of objects. • Use simple UML notations for classes and associations. • Use arrays. • Use inheritance. • Use simple I/O operations without corresponding exception handling. • Explain simple test methods and use these in simple examples. • Work in groups to design a smaller software system based on a problem description in a predefined task and implement the most important parts of this design. • Use simple time and activity planning of a project progress. 	<ul style="list-style-type: none"> • Plan, control and carry out a small software project in project groups • Describe important roles in a project group • Carry out requirement specifications • Design og programs, processes and modules • Develop smaller programs based on a particular design • Use configuration management • Develop program documentation • Plan, carry out and document user and Unit test • Evaluate own and others work based on review techniques • Prepare a report which documents the product

The actual evaluation questions in form A used for both courses are presented in Table 2. The student has the possibility to rate each question between 1 and 5, where 1 means that the student strongly disagrees with the underlying statement and 5 means that the student strongly agrees with the statement. For question A.1.6 a 1 corresponds to much more and a 5 to much less, while for A.1.7 a 1 corresponds to too high and a 5 to too low. In a sense for

these two questions a 3 corresponds to satisfactory and anything else (higher or lower) corresponds to less satisfactory. Therefore we will also consider a transformation of the two variables corresponding to A.1.6 and A.1.7 namely: $5 - \text{abs}(2x - 6)$. Then a value of 5 means “satisfactory” and anything less means “less satisfactory”.

Table 2
Questions in course evaluation Form A.

	Question
A.1.1	I think I am learning a lot in this course (1=disagree strongly, 5=agree strongly)
A.1.2	I think the teaching method encourages my active participation (1=disagree strongly, 5=agree strongly)
A.1.3	I think the teaching material is good (1=disagree strongly, 5=agree strongly)
A.1.4	I think that throughout the course, the teacher has clearly communicated to me where I stand academically (1=disagree strongly, 5=agree strongly)
A.1.5	I think the teacher creates good continuity between the different teaching activities (1=disagree strongly, 5=agree strongly)
A.1.6	5 points is equivalent to 9 hours per week. I think my performance during the course is (1=much more, 5=much less)
A.1.7	I think the course description's prerequisites are (1=too high, 5=too low)
A.1.8	In general, I think this is a good course (1=disagree strongly, 5=agree strongly)

Filling in the questionnaire is not mandatory at DTU. However, students are urged to respond by means of a “nag screen”. Unfortunately the response rate is often still low, sometimes as low as 10-15%. For the case considered it ranges between 13% (for 2010) and 42% (for 2008 and 2009). In order to ensure sufficient data for the analyses three years of course evaluations (2008, 2009, and 2010) are combined and analysed together.

Using an anonymous key it is possible to pair the evaluations for every single student between the two courses. This results in a total of 33 observations for 2008 (14), 2009 (14) and 2010 (5) combined. An overview of the numbers of students who could answer, who did answer, answering percentages and number of students, who evaluated both courses, is seen in Table 3.

Table 3
Basic statistics on numbers of students evaluating the courses: “Introductory Programming” (02312) and “Development methods for IT-Systems” (02313)

Year	2008		2009		2010	
	02312	02313	02312	02313	02312	02313
Course #	02312	02313	02312	02313	02312	02313
# enrolled	75	94	50	74	62	90
# evaluated	23	35	21	23	8	15
Answer %	30.7%	37.2%	42.0%	31.1%	12.9%	16.7%
# evaluated both	14		14		5	

METHODS

In all statistical tests p-values of 5% or less are considered significant while p-values between 5% and 10% are considered indicative. Parametric analysis more or less implying use of the normal distribution is employed although the data are clearly not normal. However, with a suitably large number of observations this is considered a reasonable approximation.

Descriptive statistics of the sample are given as counts, sample means and standard deviations.

Possible differences in mean level of the answers with respect to “year” and “course” are tested using three-way analyses of variance with “student” as the third factor. The model contains the fixed effects: “year”, “course”, and the interaction “year*course”. The student effect is modelled as random and nested below “year” as “student(year)”. The effects: “course” and “year*course” are tested against residual error, while “year” is tested against “student(year)”. Significance of “year” means the level of the answers differs over the years regardless of course. Likewise significance of “course” means the level of the answers differs for the two courses regardless of year. Finally, a significant interaction between year and course indicates that the mean differs more (or less) than linearly for the combination of year and course. This is sometimes called super- and supra-additivity, respectively.

It is noted that if all observations had been from the course pair from the same year then the above analysis could have been performed using a pairwise t-test.

A so-called canonical correlation analysis [11], [12] is performed in order to assess the degree of association between the questionnaires in the two courses. Canonical correlation analysis is a statistical technique which can be considered as an extension of ordinary linear regression analysis. Ordinary linear regression analysis relates one response variable “y” to a linear combination of a number of “x” variables. Canonical correlation analysis extends this by allowing a number of “y” variables. It works by relating a linear combination of the “y” variables to a linear combination of the “x” variables such that the correlation between them is maximal. This is the first canonical correlation. It is possible to extend this scheme to several canonical correlations. The corresponding pairs of sets of weights can be interpreted as the importance of the different questions in the questionnaire.

RESULTS

As a general overview one may consider simple averages of the scores for the different questions. These indicate that the courses are generally considered satisfactory by the students.

As seen from Table 3 the response rate is low for each course and year. This of course means the response rate for the combination also runs the risk of being low.

From the simple descriptive statistics presented in Table 4 it is evident that there is an overall difference in student rating between the two courses. The “Introductory Programming” course, get lower rates than “Development methods for IT-Systems” course.

Ten three-way analyses of variance, one for each of the questions, with “year”, “course” and “student” as factors were performed. The first null-hypothesis was that there was no year-effect (difference between years). The second null-hypothesis was that there was no course-effect (difference between courses). The third null-hypothesis was that there was no effect of the interaction between year and course. The results of the tests are shown in table 5.

A canonical correlation analysis was performed for the 33 observations at hand. Our interest was to investigate the (correlation) structure of the data between the two courses. Since a difference in mean between years has been detected above, we subtracted off the mean for each year from each answer. (The canonical correlation analysis automatically adjusts for the course means.)

Table 4
Sample descriptive statistics, all years

Variable	Introductory Programming (02312)			Development methods for IT-Systems (02313)		
	N	Mean	Std Dev	N	Mean	Std Dev
A.1.1	33	3.48	1.30	33	4.12	0.96
A.1.2	33	3.24	1.39	33	3.88	1.02
A.1.3	33	3.39	1.12	33	3.36	1.11
A.1.4	33	2.45	1.50	33	3.39	1.37
A.1.5	32	2.78	1.36	33	3.85	1.09
A.1.6	33	2.97	0.88	33	3.21	0.82
A.1.6T	33	3.85	1.33	33	3.97	1.33
A.1.7	33	2.94	0.50	33	2.97	0.47
A.1.7T	33	4.51	0.87	33	4.70	0.88
A.1.8	33	3.27	1.18	33	3.88	1.05

Table 5
P-values of effects in three-way analyses of variance (ANOVA) for each question.
Significances at the 5% level shown in boldface.

Question	Year	Course	Year*Course
A.1.1 (Learning a lot)	0.0003	0.0037	0.2644
A.1.2 (Activation)	<0.0001	0.0015	0.0354
A.1.3 (Material)	<0.0001	0.4341	0.0756
A.1.4 (Feedback)	<0.0001	0.0003	0.1187
A.1.5 (Continuity)	0.0002	0.0003	0.2122
A.1.6 (Workload)	0.4992	0.5992	0.0178
A.1.6T (Workload, transformed)	0.6253	0.4228	0.6233
A.1.7 (Prerequisites)	0.4613	0.8391	0.6353
A.1.7T (Prerequisites, transformed)	0.3451	0.5265	0.2521
A.1.8 (General)	<0.0001	0.0027	0.4415

A canonical correlation analysis is concerned with the analysis of all variables simultaneously and requires that observations do not contain missing values. In the data set at hand there is a single missing value for question A.1.5 for the “Introductory programming” course. The missing value was substituted by the mean in order to include the observation in the analysis. Alternatively more elaborate methods like imputation might be used.

In order to ease interpretation the transformed values of questions A.1.6 and A.1.7 were used.

The canonical correlation analysis results in one pair of components being indicative (significant at the 10% level but not at the 5% level), with a p-value of 0.0825. This means no firm conclusions should be drawn. However, we may still try to interpret the results. The results are shown in Table 6. The interpretation is performed by considering the largest weights first. These are seen for questions A.1.1 (positive for both courses), A.1.3 (contrast between courses), A.1.4 (negative for both courses), A.1.6T (contrast between courses), and A.1.8 (contrast between courses).

Table 6
Standardized canonical coefficients for the two courses.

	Introductory programming	Development methods
A.1.1 (Learning a lot)	0.58	0.65
A.1.2 (Activation)	-0.23	-0.15
A.1.3 (Material)	-0.44	0.95
A.1.4 (Feedback)	-0.34	-0.63
A.1.5 (Continuity)	-0.23	0.21
A.1.6T (Workload, transformed)	-0.56	0.43
A.1.7T (Prereq., transformed)	-0.12	-0.05
A.1.8 (General)	0.74	-0.38

In order to ease interpretation a reduced set of variables is produced by removing variables with small coefficients one at a time and re-running the analysis each time. With only five variables left all coefficients are greater than 0.5. The result is shown in table 7. We note the same variables as before except variable A.1.8 are represented.

Table 7
Standardized canonical coefficients for reduced variable set for the two courses.

	Introductory programming	Development methods
A.1.1 (Learning a lot)	0.92	
A.1.2 (Activation)		
A.1.3 (Material)		0.94
A.1.4 (Feedback)	-0.71	-0.68
A.1.5 (Continuity)		
A.1.6t (Workload, transformed)	-0.67	
A.1.7t (Prereq., transformed)		
A.1.8 (General)		

DISCUSSION

The overall result of the three-sided analysis of variance (Table 5) was that all questions, except questions A1.6 and A1.7 and their transformed versions, showed that “year” was extremely significant. For “course” the overall result is that all questions except question A.1.3 and questions A1.6 and A1.7 and their transformed versions, were very significant. The relevant mean values for each course may be judged from table 4. It is noted that for questions which are found to be significant, the difference is towards more satisfaction with the course “Development methods for IT-Systems”. For the interaction term only questions A.1.2 and A.1.6 showed significance. The significance is nowhere near that of the main-effects “year” and “course” and for simplicity the interaction effect will therefore not be considered further here.

The standardized coefficients from the full set and the reduced set canonical correlation analyses are shown in Tables 6 and 7 respectively. We can interpret the simplified result as follows: In “Introductory programming” the student thinks she is learning a lot, she does not think she is receiving very much feedback, and she has an unsatisfactory workload. In “Development methods” the same student tends to think the material is good, and she is not receiving very much feedback in this course either. The complete result in Table 6 basically gives the same interpretation, but in more detail.

Thirty-three (33) observations with evaluation information from the same student in both courses in the same year were available for analysis. The low number is unfortunate, but a consequence of the rather low response rates seen in many professional bachelor courses at DTU. Therefore three years of evaluations were analysed together. Furthermore, small courses also run the risk of having very few student evaluations even at high response rates. In this case combining the evaluations from several years may be the only possibility.

Generally it is a benefit that the observations are paired, since this makes it possible to eliminate much of the variation between students. Therefore, inferences about differences between courses can be expected to be more valid, than had different students evaluated the two courses.

CONCLUSION

This paper discusses possible use of student course evaluations on a pair of courses developed to comply with the CDIO concept. It is seen that both similarities and differences in the evaluations of the courses can be found. The similarities and differences can in part be used to assess if the CDIO concept has been implemented as it was intended and possible adjustments can be suggested.

The use of paired data more easily and validly highlights differences between courses with respect to mean value. Here methods like the paired t-test and more generally analysis of variance may be employed. Also it gives the unique possibility of finding associations between course evaluations by means of techniques like canonical correlation analysis.

In the case analysed an obvious and consistent shift in mean between the courses was seen using analysis of variance. Also shifts in mean from year to year were shown to occur. Before further analysis the data was adjusted for this. Finally, insight into the structure between courses was achieved by means of canonical correlation analysis. Both pieces of information are expected to help in further developing the courses and the interaction between them.

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PEER LEARNING WITH SMALL MEANS: A CASE STUDY OF IMPLEMENTING PEER LEARNING IN A LABORATORY EXERCISE

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ABSTRACT

Peer learning in teaching is a common method which makes students share their problems and learn from each other. It is often used to increase students' understanding and level of deep learning. In this study, the peer learning concept has been applied to a laboratory exercise and a comparative study has been performed. The study consists of two cases, a reference group, which performed the exercise in a traditional way, and a peer learning group, which performed the exercise in a modified way. In the peer learning group, the students were encouraged to ask each other for help and an additional presentation was added in order to further increase the interaction between students. The outcome was evaluated through classroom observations, a questionnaire, and a short knowledge test. The results show that the peer learning approach had different positive effects. When the students were instructed to ask each other for help, there was an apparent change in the students' behaviour. The students in the peer learning group were more active and more creative compared to the reference group. They also had better results on the knowledge test and were more satisfied with the exercise. This demonstrates that small changes to an existing laboratory exercise can increase the understanding, involvement and creativity of the students. In this case, this was also achieved without an extended workload on the teacher.

KEYWORDS

Peer learning, laboratory exercise, case study, increased learning, cooperation

INTRODUCTION

During the last decade, requirements have been emphasized on development of generic skills for students of all levels. The three main categories of generic skills are basic skills, interpersonal skills and peer-related skills. Their importance is clearly stated in the eight key competences for lifelong learning provided in the European Union legislation [1] from 2006 and the new Swedish degree of ordinance from 2007. Generic skills are especially emphasized in engineering education, with the CDIO initiative as a good example in this development. In engineering educations laboratory exercises are widely utilized as a way to develop these skills as they are much more practical and professionally related than many other learning environments that the student might work in during his or her study time. Still, there is a notion that students still find and see themselves as receivers of information, rather than active learners or problem solvers.

A method that has gained a lot of interest lately inter alia regarding the benefits of generic skills development is peer learning [2], [3]. Peer learning is something that has always occurred as humans interact and can be defined as “the acquisition of knowledge and skill through active helping and supporting among status equals or matched companions” [3]. In Vygotsky’s theories about the zone of proximal development (ZPD) a person’s competence is not of interest. Instead, the focus is on her potential understanding and action [4]. Being outside the ZPD really means confining oneself to activities that involve doing what is already known. However, as pointed out by Säljö [5], there is always unspoken knowledge that can be understood and used via interaction in the ZPD. In Vygotsky’s terms, this zone is the gap between what students already know and what they achieve with the guidance from a teacher or a more capable peer. Consequently, it is important to assist the student who wants to learn by providing communicative support or scaffolding [6]. The metaphor of scaffolding is often defined as the provision of structures within the ZPD to bridge the previously mentioned gap. Topping reports that the effects of peer learning have been positive when well structured and well implemented [3]. In this study we were arranging the structure of a laboratory exercise to increase each student’s interaction with a status equal, but more capable peer. This was an effort to bring the students in the ZPD through scaffolding from their peers.

The aim was to investigate if minor changes to a laboratory exercise could improve the learning outcomes with respect to knowledge, skills and attitudes. The minor changes needed to be feasible to perform for the instructor, without an extended workload.

METHOD

The present study is a comparison of a group of students performing an ordinary laboratory exercise (the reference group) and a group of students performing the same laboratory exercise in a peer learning situation. The groups were evaluated by the use of a questionnaire, a knowledge test and classroom observations.

The study was performed in the laboratory exercise “*Optical grating and mass spectrometry*”, which is part of the course “*Electromagnetism and wave motion*”. The students attending the course, which was given in Swedish, were second-year students in chemical engineering at KTH Royal Institute of Technology. A total of 20 students of mixed genders took part in the study, ten in each laboratory exercise group.

The structure of the laboratory exercise

The reference group performed the laboratory exercise in the standard manner:

1. In advance the students got a laboratory instruction manual, including theory, practical guides and the main tasks. They were told to read it before the laboratory exercise.

2. When the class started and the students entered the laboratory exercise classroom, they seated themselves at one of five benches with laboratory equipment, two students at each bench.
3. The instructor announced that the exercise was a part of a study for evaluating laboratory exercises and informed the students that they should fill in a questionnaire and perform a short knowledge test at the end of the exercise. One more person was present in the classroom and presented as an observer for the study. (Step 3 was part of the study and is not normally performed.)
4. The exercise started with the instructor giving a short introduction of the most important theory, functionality of the equipment, and practical issues for the exercise.
5. The students performed the tasks described in the instructions. The first task was to calibrate the instrument followed by three problems: Problem A, B, and C. During this time the instructor was available for questions.
6. As each pair finished the exercise they were asked by the observer to fill out the questionnaire and perform the knowledge test for which they were allowed to use 10 minutes.

Two changes were introduced to the peer learning group compared to the reference group and an overview of the structure can be found in Figure 1. Both of the changes aimed to increase student-to-student interactions. First, the students were instructed to help each other between the pairs. Secondly, the structure of the exercise was changed in order to introduce cooperation between pairs. The changes were introduced at step 4 and 5, as described below.

The peer learning group performed the laboratory exercise in the following manner:

- 1-3. Same as for the reference group.
4. The exercise started with the instructor giving a short introduction of the most important theory, functionality of the equipment and practical issues for the exercise. The instructor ended by saying: "If you have any questions during the lab, before turning to me with your issue, please ask another student pair to see if they might have encountered a similar problem. As you know, explaining is a good way to learn. If many share the same problem, we can discuss it together."
5. The students were told by the instructor to start by calibrating the equipment, and when finished they would get a new task. The pairs were not expected to finish the calibration at exactly the same time, so of all five pairs in the room, the two pairs finishing first were assigned problem A and the three other pairs were assigned problem B (slightly less difficult than problem A). When all groups had solved their first task (A or B) they were instructed to explain their task, method and solution to another pair. They were also told that they would need the calculated values from each pair in order to calculate a mean value for the whole group, meaning that all groups would have to solve both problems. Two tables with papers and colored pens were set up beforehand for the purpose of these discussions, one table for two pairs and the other one for three pairs. After finishing the discussion the students went back to their benches and performed the task just described to them (Problem A or B). After solving this problem all pairs simultaneously performed problem C. After all problems were solved and mean values were calculated the instructor led a short group discussion about the results.
6. Same as for the reference group.

Borglund has reported that when several pairs of students work on the same problem, it is common that they struggle with the same issues without discussing it with other pairs [7]. By explicitly instructing the students to cooperate we intentionally tried to avoid that type of situation. Also, a commonly emphasized problem associated with peer learning is that group dynamics can become destructive due to competence threats between peers [3]. Buchs et al.

report that providing students with complementary information instead of identical information reduces confrontations and competence threat [8]. This is what we aimed to accomplish in the peer learning group by the discussion of problems A and B. Providing the students with the common task of calculating a mean value for the problems is another incitement for making an effort to help each other.

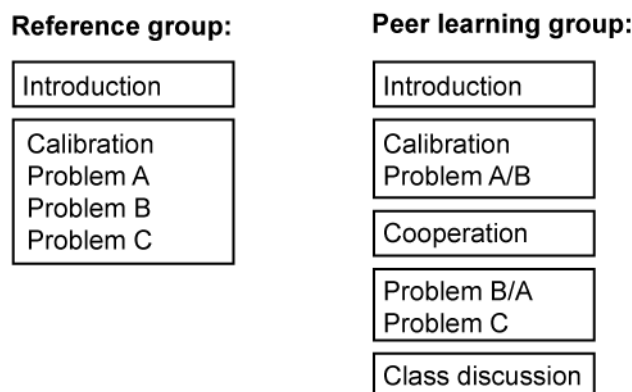


Figure 1. Comparison of the structure of the exercise for the reference group and the peer learning group. Borders are used here to separate the parts, and indicate an intervention by the instructor.

Data collection

To be able to assess the difference between the two groups three methods of data collection were used: observations, a questionnaire, and a knowledge test. The students were informed about the questionnaire and the test at the beginning of the session, as previously described. They were however not aware of the existence of a reference group and a peer learning group.

To collect observations, one extra person, the observer, was present in the classroom during the exercise. The task of the observer was to observe and make notes of the students' behaviour during the exercise. In addition to making qualitative observations, the observer also counted the number of questions being raised to the instructor. The use of an observer sitting in on laboratory sessions has previously been used by for example Magin and co-workers [9].

The questionnaire, which was anonymous, was filled out by the students at the end of the exercise. It consisted of 12 questions, of which 1-3 were introductory questions, 4-8 treated student satisfaction and involvement, 9-10 were about received assistance, and 11-12 evaluated the reporting and presentation of the results of the exercise.

In order to estimate the level of deep learning obtained by the students, the exercise finished with a short knowledge test, for which the students were allowed 10 minutes to finish. The students were asked to fill in their name on the test, in order to increase their motivation even though it was pointed out that the test did not affect their grades. The knowledge test consisted of five questions in total, and was designed to cover the most important concepts of the exercise. The correction of the test was blind, i.e. the person who corrected the test could not trace if a student belonged to the reference group or the peer learning group. Each answer was awarded zero, one or two points depending on the quality of the answer and the sum was calculated for each individual. Mean values and standard deviations were calculated for both groups, and a Wilcoxon's rank sum test was performed.

RESULTS

The results from the questionnaire, knowledge test and classroom observations are reported below.

Questionnaire

Each student indicated their level of agreement to the 12 statements below:

Introductory questions

1. I read the lab instructions carefully before the lab
2. I consider myself to have knowledge about the subject before the lab
3. I believe that the lab content is relevant to the course

Student satisfaction and involvement

4. I am more curious about the topic now than before the lab
5. I am satisfied with the structure of the lab
6. I felt involved in the lab
7. I felt that I could absorb the contents of the lab
8. I was given enough time for conducting the lab

Assistance

9. I was given enough help from the instructor
10. I was given enough help from my fellow students to handle the tasks in the lab

Presentation of results

11. The fact that tasks would be presented to the instructor motivated me to understand the content while experimenting
(Note: In the questionnaire given to the peer learning group the word instructor was changed to fellow students.)
12. The presentation process increased my understanding of the lab

Figure 2 shows the mean level of agreement to the statements in the questionnaire, where 1 represents the lowest level of agreement and 6 the highest. The mean level of agreement ranges from equal to 0.7 higher in the peer learning group for all the 12 statements except statements 3 and 9.

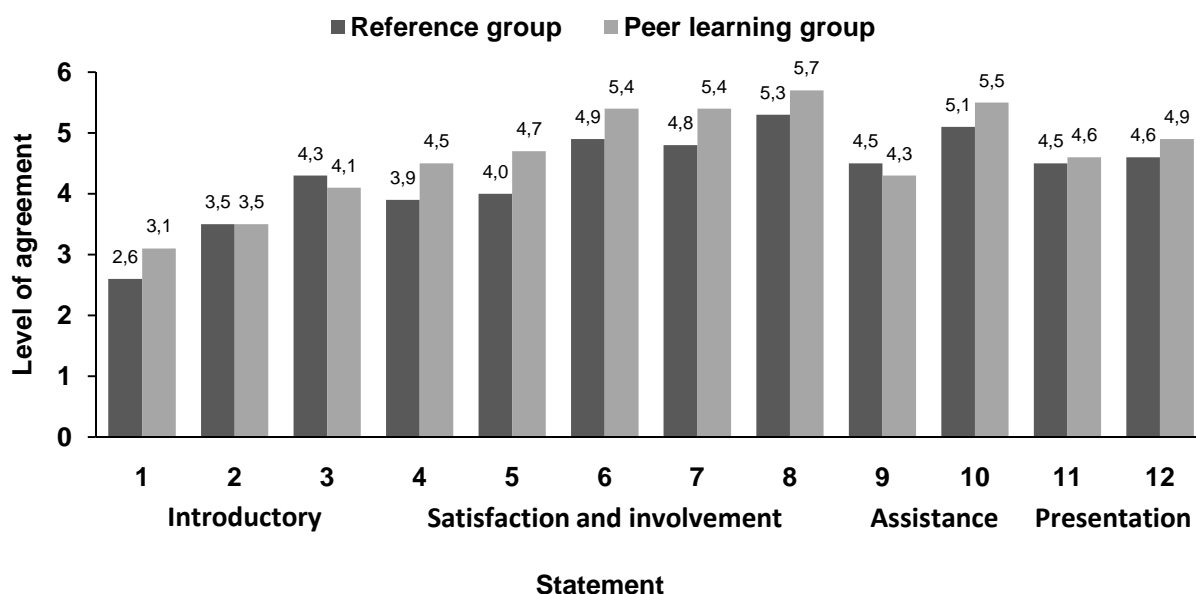


Figure 2. The results from the questionnaire.

In general the differences in each question between the two groups are minor. We can however distinguish some trends suggesting generally higher levels of agreement to most statements for the peer learning group. The major differences are found in the statements 4-6 regarding the students' satisfaction and involvement. This indicates that the students in the peer learning group were more curious about the subject, more satisfied and more involved compared to the reference group.

Knowledge test

Figure 3 shows that the average score on the knowledge test was 6.9 in the peer learning group, and 5.2 in the reference group. The test result for the peer learning group was higher on each of the five test questions, with the difference ranging from 0.1 to 0.6 (out of 2). Assuming no group difference, a two-sided Wilcoxon rank-sum test yields a p-value of roughly 0.06, indicating significance on the 10-percent level.

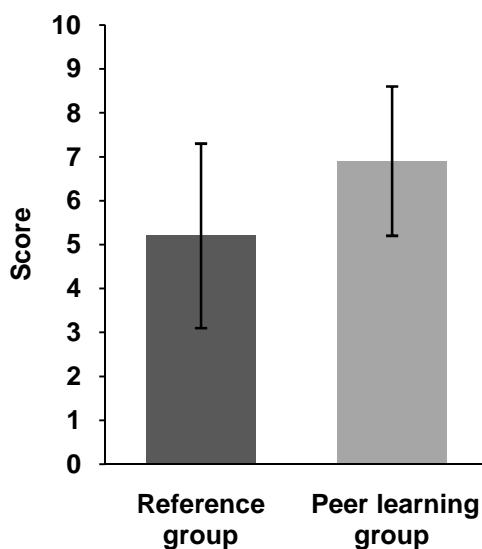


Figure 3. Diagram illustrating the results from the knowledge test. The mean value and the standard deviation was 5.2 and 2.1 for the reference group, and 6.9 and 1.7 for the peer learning group.

Observations

Some examples of observed events in the two groups are listed in Table 2 below.

Table 2. Observed events.

Reference group	Peer learning group
Initially a large confusion about what to do.	Initially a large confusion about what to do.
Most students asked the instructor for help when a problem occurred without trying to solve it themselves first. One group even tried to ask the observer for help.	Most questions were asked in the beginning, some of those were redirected to another student pair and some were answered by the instructor and discussed in front of 2 or more pairs.
Students spent a lot of time just waiting for the instructor to answer their question without doing anything themselves.	The students were engaged in their tasks.
Students generally sat down on their chairs. There was little movement in the classroom.	A lot of movement in the classroom, with students asking other groups for assistance. At one instance a pair sitting in one corner of the room walked to the other side of the classroom knowing the group sitting there had encounter their problem previously.
Only discussion within the pairs. Very few interactions between pairs, although in a few cases students asked the pair being closest to them a question.	The students showed no signs of dislike when being asked a question by another pair.
Some questions assigned to the instructor were aimed at finding out the "correct answer" to the problem/question.	The students showed more signs of creativity, e.g. one pair attached the cord of the mouse to the monitor in order to improve a visually estimated curve fitting.
One group which was falling behind needed a lot of assistance towards the end.	No group was falling behind.
It took between 2 hours and 45 minutes to 3 hours and 15 minutes for everyone to finish the exercise.	All pairs finished the lab after 2 hours and 40 minutes.
A total of 50 questions were raised to the instructor during the laboratory exercise.	A total of 7 questions were raised to the instructor during the laboratory exercise.
The constant asking of questions resulted in a very stressful situation for the instructor.	The instructor was able to step back and monitor the progress of the group.

During the laboratory exercise the students seemed to have the intention to work together and solve problems in the group. In the reference group the students hesitated to ask their peers, perhaps having the notion that it was not allowed. In the peer learning group on the other hand, once the students were told that they were allowed to ask their peers questions they acted as they usually do outside the classroom when solving problems together, for example when forming informal study groups.

DISCUSSION AND CONCLUSIONS

Our study aimed at investigating if minor changes to a laboratory exercise could improve the learning outcomes with respect to knowledge, skills and attitudes. The structure of the exercise was changed and the students were encouraged to assist each other in their work.

The knowledge test indicated increased learning, and the questionnaire revealed positive attitudes in the peer learning group. The observer reported classroom activities in the peer learning group that are essential for developing generic skills.

The restricted number of subjects could be seen as a limitation of our study. On the other hand the two groups were composed randomly. We regard the utilization of several evaluation methods as strength, as well as that the results from all of them support the general notion of an improved laboratory exercise.

The peer learning group performed better on the knowledge test. The increased level of understanding indicates that a more participative approach stimulates deep learning, which is in accordance with the work done by Biggs and Tang [10] and Bain [11].

The questionnaire indicated that the students in the peer learning group felt more curious about the subject, more satisfied and more involved compared to the reference group. It is also worth noting that the peer learning group felt that they could absorb the content of the exercise (statement 7) at the same time claiming that they received less help from the instructor compared to the reference group. Even if the students perceived that they had not received sufficient help from the instructor, they thought that they had assimilated the content of the exercise. This suggests that knowledge had been achieved working with peers, through cooperation and peer teaching – a situation to be compared to learning within the ZPD [4].

From the observations we conclude that the students in the peer learning group acted in a way they were familiar and comfortable with. When being more passive learners, as in the reference group, the standard classroom environment prevents the students from using their natural and self-obtained learning skills. One should therefore strive towards creating laboratory exercises where the classroom is an environment for natural and efficient learning activities. Crouch and Mazur [12] also state that students develop complex reasoning skills most effectively when actively engaged with the material, and that cooperative activity engages students effectively.

There was a major difference in the amount of questions raised to the instructor by the two groups. In the peer learning group the students asked their peers for help, which made them move forward solving the problem without spending time waiting for the instructor. This made it possible for the instructor to get a better overview of the progress of the group and to minimize the stress combined with repeatedly answering questions.

Changing the structure of the exercise and creating natural tollgates decreased the risk of students getting behind and losing interest. By making everybody end at the same time it was possible to gather all the students to discuss the results. This short discussion might also have contributed to the better performance of the peer learning group, since the students had a chance to structure their thoughts and discuss difficult parts to gain higher levels of deep learning.

We would also like to convey that this study resulted in a continuation of the peer learning concept in this laboratory exercise. Although not part of this study, similar effects as those reported by the observer in this study have been observed by the instructor for the subsequent groups.

In conclusion, with a small change of structure, and by encouraging students to ask each other for help, improvements to a laboratory exercise could be made. The results demonstrate that a peer learning approach is an effective way of improving students' knowledge and skills. The cooperation allows students to develop their own personal and professional skills and attitudes, which is an integral part of the CDIO initiative.

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CDIO Standards and Quality Assurance: From Application to Accreditation

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ABSTRACT

With so many Collaborators in so many countries and regions of the world it is essential that the CDIO Council promulgate processes to assure internal and external stakeholders that member institutions and programs are adhering to the 12 CDIO Standards. The Standards are what make CDIO a unique initiative and that provide a vehicle for realizing the CDIO vision *to transform the culture of engineering education*. Therefore, the Council has developed five quality assurance processes that begin with the application to become a CDIO Collaborator and include self-evaluation, certification, and accreditation based on the CDIO Standards.

KEY WORDS

CDIO standards, application, self-evaluation, CDIO study, certification, accreditation

In the 1980s and 1990s, engineering leaders in industry and government, along with university program leaders, began to discuss improvement in the state of engineering education. These discussions were stimulated by the realization that, over the preceding twenty to thirty years, engineering education program evolved from a practice-based to an engineering science-based model. The intended consequence of this change was to offer students a rigorous, scientific foundation that would equip them to address unknown future technical challenges. The unintended consequence of this change was a shift in the culture and context of engineering education. This shift diminished the perceived value of key skills and attitudes that in the past had been the hallmark of engineering, and were still critical to practice. Clearly, engineering education and real-world demands on engineers have drifted apart over the last 50 years. (See Crawley et al [1] and the CDIO website <<http://www.cdio.org>>.)

Realizing that this widening gap must be closed, leading engineering schools across the globe have established the Conceive-Design-Implement-Operate Initiative (CDIO™): A worldwide collaborative intended to foster a new vision of engineering education. The CDIO Initiative, begun in the early 2000's has as its vision *to transform the culture of engineering education, producing a new synthesis of engineering science and practice, informed by scholarship on learning*.

CDIO is based on a commonly shared premise that engineering graduates should be able to Conceive – Design — Implement — Operate complex value-added engineering systems in a modern team-based engineering environment to create systems and products. The CDIO Initiative thus offers an education model stressing engineering fundamentals, set in the context of the Conceiving — Designing — Implementing — Operating process. The CDIO Initiative's goals are to educate:

- students to master a *deeper working knowledge* of the technical fundamentals,
- engineers to lead in the *creation and operation* of new products and system, and
- future researchers to understand the importance and *strategic value* of their work.

The CDIO Initiative was specifically designed as a template that can be adapted and adopted by any university engineering school. By 2010, there were over 50 collaborating institutions in over 25 countries worldwide in the CDIO Initiative including a number of programs outside traditional engineering disciplines.

Because CDIO is an open architecture model, it is available to all university programs to adapt to their specific needs. CDIO has open and accessible channels for disseminating and exchanging resources. Participating universities and programs (“Collaborators”) regularly develop materials and approaches to share with others. CDIO collaborators have assembled a unique development team of curriculum, teaching and learning, assessment, design and build, and communications professionals. They are helping others to explore adopting CDIO in their institutions. (Extensive information about the CDIO Initiative may be found at <<http://www.cdio.org/>>.)

The International CDIO Council oversees the CDIO Initiative. The International Council consists of the original developers (Chalmers University of Technology, Linköping University, and KTH Royal Institute of Technology in Sweden and The Massachusetts Institute of Technology in the United States), the early collaborators (Technical University of Denmark; Queen's University, Belfast, Northern Ireland; Queen's University, Ontario, Canada; and The US Naval Academy, Annapolis, Maryland), and one representative of each of the CDIO Regional Centers (North America, Latin America, UK-Ireland, Nordic, South African, Australia and New Zealand, and the Asian Regional Group with affiliated Regional Centers). The International Council is responsible for developing and implementing policies and procedures related to the governance and organization of the CDIO Initiative.

In January 2004, the CDIO Initiative adopted 12 standards to describe CDIO programs. These guiding principles were developed in response to program leaders, alumni, and industrial partners who wanted to know how they would recognize CDIO programs and their graduates. As a result, the CDIO Standards define the distinguishing features of a CDIO program, serve as guidelines for educational program reform and evaluation, create benchmarks and goals with worldwide application, and provide a framework for continuous improvement. The standards may also be used as a framework for quality assurance purposes as discussed in this paper.

The 12 CDIO Standards address program philosophy (Standard 1), curriculum development (Standards 2, 3 and 4), design-implement experiences and workspaces (Standards 5 and 6), methods of teaching and learning (Standards 7 and 8), faculty development (Standards 9 and 10), and assessment and evaluation (Standards 11 and 12). The CDIO Standards address 12 characteristics of engineering education that define the CDIO approach:

- Standard 1 The Context
- Standard 2 Learning Outcomes
- Standard 3 Integrated Curriculum
- Standard 4 Introduction to Engineering
- Standard 5 Design-Implement Experiences
- Standard 6 Engineering Workspaces
- Standard 7 Integrated Learning Experiences
- Standard 8 Active Learning
- Standard 9 Enhancement of Faculty Competence
- Standard 10 Enhancement of Faculty Teaching Competence
- Standard 11 Learning Assessment
- Standard 12 Program Evaluation

Each standard is elaborated with a description and a rationale. The description elaborates the statement of the standard, explaining its meaning. It defines significant terms and provides background information. The rationale highlights reasons for the adoption of the standard based on educational research and best practices in engineering and higher education. The rationale explains ways in which the standard distinguishes the CDIO approach from other educational reform efforts. The CDIO Standards v 2.0 are listed in the Appendix and the full descriptions and rationales may be found at <http://www.cdio.org/implementing-cdio/standards/12-cdio-standards>.

With so many Collaborators in so many countries and regions of the world it is essential that the Council promulgate processes to assure internal and external stakeholders that member institutions and programs are adhering to the 12 CDIO Standards. The Standards are what make CDIO a unique initiative and that provide a vehicle for realizing the CDIO vision *to transform the culture of engineering education*. Therefore, the Council has developed five quality assurance processes that answer the following questions:

- How can the Council make sound decisions about new members (i.e., potential Collaborators)?
- How can Collaborators (institutions and programs) evaluate their efforts and guide continuous improvement relative to the standards, and determine if the resources that are being put into CDIO are having the desired impact?
- How can the Council determine the current status of the Initiative, the progress that has been made over time in the adoption of the Standards across Collaborators, and the world-wide impact being achieved by the Initiative?
- How can CDIO Collaborators at the Regional Level certify a Collaborator's level of adoption of the CDIO Standards?
- How can the CDIO Standards be used to meet accreditation expectations intended to assure internal and external stakeholders that CDIO Collaborator institutions and programs are of the highest quality?

THE APPLICATION PROCESS

The CDIO Council oversees the CDIO Initiative application process. When an institution wishes to join the CDIO Initiative it must develop a proposal in response to the following questions:

- Why does your institution wish to join the CDIO Initiative?
- What goals do you hope to achieve?
- To which of your programs do you plan to initially apply CDIO?
- How do you expect CDIO to impact these programs?
- What experience do you have in educational reform (engineering or otherwise) at your institution that could form a foundation for your work as a CDIO Collaborator and that could contribute to the CDIO Initiative in general?
- As a CDIO Collaborator, how might you reach out to other local and regional higher education institutions and programs, participate in regional activities, and contribute to worldwide CDIO efforts?
- What level of commitment and support do you have from your program, school or college, and institutional leadership? (Attach supporting letters, if applicable.)
- Who will be the key two to five participants in your effort? (Attach short CVs as appropriate.)

A prospective member formally applies first to its Regional Council. The Regional Council consists of the leaders of each of the member institutions (Collaborators) in the Regional Center. Typically, a presentation to support the application will be made by the prospective member either during a regional meeting or teleconference.

The purpose of having the Regional Council initially vet proposals is to take advantage of the first-hand knowledge that the Regional Collaborators have regarding institutional and programs in their region. In essence, this is the beginning of the CDIO quality assurance process, which is based on the professional judgement of its members.

If approved by the Regional Council, then the proposal is forwarded to the International CDIO Council for action either during a teleconference or, if at all possible, at an international meeting. All institutions that are approved by the International Council to join the CDIO Initiative are designated as CDIO Collaborators.

CDIO COLLABORATOR SELF-EVALUATION

The second quality assurance process is the CDIO Program Self-Evaluation. Its goal is to give CDIO Collaborators the opportunity to reflect on their current implementation of CDIO, relative the 12 CDIO Standards, and to provide guidance for the continuous improvement of their program(s). Within six months of joining the CDIO Initiative, it is expected that an institution and the programs to which it plans to apply CDIO will create a baseline for their efforts by conducting a CDIO Program Self-Evaluation. Self-evaluation by Collaborators is intended to set them on a journey to full implementation of the CDIO Standards.

The central document for the self-evaluation process is *The CDIO Standards v 2.0 (with customized rubrics)* <<http://www.cdio.org/implementing-cdio/standards/12-cdio-standards>>. The rubrics are intended to serve as self-evaluation benchmarks of each standard and to guide efforts to increase the level of adoption over time.

Each self-evaluation rubric is a scoring guide for evaluating levels of implementation, compliance, and/or performance related to each CDIO Standard. The rubrics consist of a six-point rating scale indicating with 0 being the lowest and 5 being the highest level of adoption. Criteria for each level are based on the description and rationale of the Standards and highlight the nature of the evidence that indicates compliance at each level. The rubrics are cumulative, that is, each successive level includes those at lower levels. For example, Level 5 that addresses continuous process improvement presumes that Level 4 has been attained.

General Rubric:

Scale Criteria

5	Evidence related to the standard is regularly reviewed and used to make improvements.
4	There is documented evidence of the full implementation and impact of the standard across program components and constituents.
3	Implementation of the plan to address the standard is underway across the program components and constituents.
2	There is a plan in place to address the standard.
1	There is an awareness of need to adopt the standard and a process is in place to address it.

0	There is no documented plan or activity related to the standard.
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The evaluation of compliance with the CDIO Standards is a voluntary self-reporting process. An Collaborator gathers evidence and uses the rubrics to rate its status with respect to adoption of each of the 12 CDIO Standards. While the rubrics are customized to each CDIO Standard, they follow the pattern of this general rubric.

A useful accompanying document is *Examples of Evidence of Compliance with the CDIO Standards v 2.0*. This document gives examples of evidence that have been provided by collaborators drawn from their program documents. It is purely advisory, but very helpful.

A third document is the *CDIO Self-Evaluation Template* (see Appendix). This serves as a guide to the process, and a record of the results of the self-evaluation. As the template suggests, a program should:

- Become familiar with each standard, its description, and rationale using *The CDIO Standards v 2.0*.
- Gather and record evidence of the level of compliance with the standard guided by samples in the *Examples of Evidence of Compliance with the CDIO Standards v 2.0*.
- Assign a ranking based on the six levels of compliance described by the customized rubric found in *The CDIO Standards v 2.0 (with customized rubrics)*.
- Identify actions that the program can take in the next year to enhance its level of compliance with the standards.

This last step is ultimately the most important as it provides concrete steps on how the program can improve over time, which embodies the spirit of the CDIO Standards and Self-evaluation Process.

CDIO INITIATIVE COLLABORATOR SURVEY

Using the same metrics as the Program Self-evaluation the CDIO Survey, the third quality assurance process is conducted periodically under the auspices of the CDIO Leadership Council to assess the overall status of the CDIO Initiative. All Collaborators as requested to complete the CDIO Self-evaluation form and to provide evidence of compliance with the 12 CDIO Standards.

A survey of CDIO collaborators was authorized in 2008 by the CDIO leadership as a follow up to an earlier study, *Evaluation of CDIO Programs Based on the CDIO Standards 2000 to 2005* [2] Twenty-three out of 27 institutions responded to the 2008 survey [3].

The survey has three main sections. The first includes demographic items about CDIO collaborating institutions and programs. The second section includes a rating of the extent to which CDIO Standards have been implemented as well as a request for descriptions of any major improvements with respect to the standards since the adoption of the CDIO approach. And the third section asks questions about the use of the CDIO Standards related to quality assurance.

Among the 23 collaborating institutions that responded to the survey, there are over 60 degree programs represented, which typically require 3 – 4 years for completion. Overall there is a fairly even distribution of programs related to their duration of involvement with CDIO, ranging from 1

to 5 years plus. In addition, there are typically 10 or fewer CDIO instructors out of 20 or more program instructors.

The number of students per cohort over the last 5 years has ranged from under 50 to over 4,700. However, most programs have 200 or fewer students in future cohorts with typically fewer than 100 graduates per cohort thus far.

A rating scale ranging from 0 (No initial program-level plan or pilot implementation) to 4 (Complete and adopted program-level plan and comprehensive implementation at course and program levels, with continuous improvement processes in place) was used to quantify the extent that the CDIO Standards had been implemented. Ratings of use consistently rise from institutions with 2 years or less experience with CDIO to those with 5 or more, except for the Standard 10 -- Enhancement of Faculty Teaching Competence.

There were many excellent examples of improvement that are related to the adoption of the CDIO Standards. As noted above, these examples are in the document, *Examples of Evidence of Compliance with the CDIO Standards v 2.0*. The last set of items asked about the extent and nature of the use of the standards regarding various quality assurance purposes; quality assurance within a program and for external accreditation were the two most often cited uses.

CDIO REGIONAL CERTIFICATION PROGRAM

The fourth quality assurance process is the CDIO Regional Certification Program. The goal of the Program is to establish an agreed-upon process in order to assure the quality of the CDIO Initiative, consistency of approaches to implementing the CDIO Standards, and protection of the CDIO brand. In addition, the CDIO Regional Certification Program is intended to provide Collaborators with a means for having the quality their efforts "certified".

In the CDIO Initiative *certification* and *accreditation* are defined as distinctly different activities. Certification here is defined as being synonymous with *attest, confirm, declare, or verify the quality* of a CDIO compliant program. In comparison, accreditation is a more stringent form of quality control synonymous with such terms as *officially state, recognize, sanction, or authorize*. Accreditation often involves both internal self-evaluation, external review by peers, and then a formal designation by a sanctioned accrediting body as will be discussed in the next section of this paper.

Certification may be important in order to establish a program's credibility within an institution or a national educational system. The CDIO Initiative and Standards are being advanced as national models and criteria for recognition, and, in some cases, special financial and other support. In this regard, national policies or practices create incentives for programs to adopt CDIO. The CDIO certification process can serve as a mechanism for determining whether a particular program is successfully implementing the CDIO Standards, and, therefore, worthy of such recognition and support. In other cases, where there are no national or regional quality assurance processes or standards, CDIO certification can serve as an independent means of verifying program quality.

All programs accepted as members of the CDIO Initiative are automatically CDIO Collaborators. The CDIO Initiative is a voluntary organization and, therefore, certification is a voluntary process of self-evaluation on the part of collaborating institutions and programs. The CDIO Regional

Certification Program's specific objective is to create a certification process with procedures, rubrics, evidence, and certification criteria related to the CDIO Standards.

Within this context, the CDIO Regional Certification Program is completely voluntary and an institution and/or program can become and remain a CDIO Collaborator never having engaged in this formal program. In addition, it is intended to be a simple and transparent process that meets the needs of both the CDIO Initiative and Collaborators.

Certification occurs at the regional level at the discretion of the CDIO Regional group. There is no international certification of programs. However, in order to provide consistency of certification processes and criteria across regions, the following procedures have been developed and approved by the CDIO Council as a means for a CDIO institution and/or program to seek certification.

1. CDIO Collaborator institutions and/or programs seeking certification notify their respective regional group.
2. The regional group appoints at least two reviewers who are independent from the program applying for certification. If there is no regional group, then reviewers may be designated at the discretion of the CDIO Council.
3. CDIO Collaborator institutions and/or programs submit a **CDIO Certification Self-Evaluation Survey** to their regional group. The survey consists of:
 - a. program demographics of the institution and/or program seeking certification (a brief narrative description of the CDIO effort, years as a Collaborator, student body currently enrolled and graduated, instructor profile, etc.);
 - b. a summary of the self-ratings for the CDIO Standards and evidence as indicated on the CDIO Self-Evaluation Template;
 - c. supporting documentation based on the specific rubrics for each Standard and the *Examples of Evidence of Compliance with the CDIO Standards v 2.0*. In general the evidence to support each of the 12 standards will be a short document not more than two pages in length.
4. A rating of **4 or higher** on CDIO Standards 1, 2, 3, 5, 7, 9, and 11 is required for **Certification**. If one of these standards has a rating of 3, a program may petition for certification. In addition, a rating of **2 or higher** is required on the other standards (4, 6, 8, 10, and 12).
5. Based on the presented evidence and other knowledge of the program, the reviewers evaluate the CDIO Certification Self-Evaluation Survey information to determine whether they agree or disagree with the ratings. The reviewers submit their comments, observations and recommendations to the regional group using the **CDIO Regional Certification Recommendation Form**.
6. After reviewing the **CDIO Regional Certification Recommendation Form**, the regional group will determine if the Collaborator may be designated as a **CDIO Certified**.
7. The duration of the certification is decided by the regional group but, in general, it should be not less than three and not more than six years.
8. A program that is certified following these procedures has the right to call itself a **Certified CDIO Program**.

CDIO STANDARDS AND ACCREDITATION

There is a growing body of cases where the reference to the CDIO Standards has had a positive influence on accreditation. Various local and national authorities and professional associations accredit programs for engineering and technology. As noted by Malmqvist [4], p. 1,

A CDIO programme needs a quality assurance system which also fulfils national requirements, and that is able to produce the evidence and documentation needed for a national evaluation with minimal additional effort. Efficient execution of this task requires understanding of the similarities and differences between CDIO Standards and national quality assurance systems.

Hanrahan [5] describes “three interacting elements [that] are involved in the provision of quality education” (p. 52). The first element is “the standards set by the accrediting body” (p.52). The second element is the program design intended to meet the standards, especially those program processes related to achieving intended educational outcomes and providing evidence that the program’s graduates attain these outcomes. The third element is the “external quality assurance process that evaluates the achievement of the programme against the standard and other criteria such as program structure, the quality of teaching and learning and the resourcing and sustainability of the programme” (p. 53). The CDIO Standards and Self-evaluation process have been used to provide the foundation for meeting accreditation expectations.

One such accreditation system is the EUR-ACE (*EUR*o*PEAN*-*AC*credited Engineer) formulated Framework Standards for the European Accreditation of Higher Education Programs in Engineering as described by Augusti [6]. Malmqvist [4] has compared the CDIO and EUR-ACE standards and drawn the following conclusions (p.1):

- The CDIO syllabus reflects a more encompassing view of engineering than EUR-ACE’s, by considering the full product/system/process lifecycle, including the implementing and operating life phases. The proficiency levels of the CDIO and EUR-ACE are, however, difficult to compare.
- The EUR-ACE accreditation requirements are extensive and include elements not addressed in the CDIO framework, e.g., concerning financial resources and decision making. The CDIO standards provide “solutions” on how to work with about $\frac{3}{4}$ of the issues raised in a EUR-ACE accreditation.
- Four of the CDIO standards (4, 5, 7, and 8) define educational elements which are not explicitly discussed in EUR-ACE accreditation requirements.
- An evaluation process based on a rating scale, such as the CDIO self-evaluation model, is more useful for continuous improvement than a threshold value scale, such as used in a EUR-ACE accreditation.

Another more specific effort by Brennan and Hugo [7] is related to meeting Canadian Engineering Accreditation Board (CEAB) expectations: “Historically, the CEAB accreditation process has been very quantitative, focusing heavily on curriculum component minimums” (p. 1). Beginning in 2005, the CEAB has moved toward a model that emphasizes continuous improvement, and more specifically, program outcomes. As a result of these changes to the CEAB’s criteria and procedures, Canadian engineering schools need to create new processes that focus on outcomes assessment and curriculum improvement. Similar to the EUR-ACE/CDIO comparison by Malmqvist; Cloutier, Hugo, and Sellens [8] analyzed the CEAB expectations and found that, “An engineering program can meet all of the CEAB Graduate Attribute requirements by addressing a subset of the CDIO Syllabus, however a CEAB accredited program may not meet all of the requirements of CDIO”(p. 1).

Rocha, Costa, and Martins [9], propose combining CDIO and EUR-ACE approaches since “CDIO is more oriented to program operation and EUR-ACE is more oriented to program manage” (p. 1). The corresponding Standards and Guidelines for Quality Assurance in the European Higher Education Area (2005) are concerned with ensuring the quality of educational processes in all higher education programs which is certainly consistent with the CDIO ideal.

Further the Portuguese National Agency for Program Evaluation and Accreditation (A3ES) provides explicit accreditation conditions. Rocha, Costa, and Martins [9] suggest a number of considerations under the following conditions that are especially important in terms of CDIO (see Appendix 2):

- Quality Assurance Mechanisms
- Teaching objectives, curricular structure and syllabus
- Organization of curricular units
- Teaching/learning methodologies

The CDIO Syllabus embodied in CDIO Standard 2, Learning Outcomes as well as the ideal of continuous improvement that underlies the CDIO Self-evaluation process are also compatible with and provide the foundation for the ABET, Inc. accreditation process (EC2000). As noted by Crawley [10] the CDIO “Syllabus can be utilized to define new educational initiatives, and it can be employed as the basis for a rigorous assessment process, such as is required by ABET” (p. 1). In addition as Brodeur and Crowley [11] note, the “CDIO program evaluation approach expands the Quality Assurance criteria of ABET EC2000 particularly in the areas of teaching and learning, and the consequent need for faculty development” (p. 219). They provide a comprehensive comparison of the CDIO Standards and the ABET evaluation criteria in EC2000 and conclude that “the 12 standards developed by the CDIO Initiative serve as a useful framework for internal program evaluation and external Quality Assurance” (p. 221) [11]. It is likely that a rigorous comparison of the CDIO Standards and most accreditation schemes will show the same types of similarities and differences.

The last example is from Sweden where the CDIO self-evaluation model was introduced into the 2005 nation-wide evaluation of higher education. In general, Swedish evaluation of higher education follows a theory-driven approach that includes conditions (inputs)-processes-results (outputs). Self-evaluation relative to the CDIO Standards was incorporated in the 2005 evaluation “as a model for engineering education development and as an instrument for continuous self-improvement” (p. 137), Malmqvist and Sadurskis [12]. The CDIO self-evaluation process and the self-evaluation rubrics described earlier, along with the rating form shown in Appendix 1 were used to guide the process. The results of this effort indicate that the CDIO Standards are relevant to a wide-range of programs and that using the Standards has the potential to improve program quality. In conclusion, Malmqvist and Sardurskis [12] found that the Standards’ “most important benefit is that they provide that basis for systematic program development” (p.141).

Along with the exponential growth of CDIO since 2005 have come concerns about quality assurance within the CDIO Initiative. The various quality assurance methods adopted by the CDIO Leadership Council described in this paper are intended to address those concerns. Together they attempt to answer the question, how can the Initiative ensure that the integrity of its *brand* is maintained?

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BIOGRAPHICAL INFORMATION

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Appendix 1: CDIO Standards and Self-evaluation Template

Institution:

Program:

Evaluators:

Date:

	CDIO STANDARD	RATING	EVIDENCE OF COMPLIANCE	ACTIONS
1	CDIO as Context Adoption of the principle that product and system lifecycle development and deployment – Conceiving, Designing, Implementing and Operating - are the context for engineering education			
2	CDIO Syllabus Outcomes Specific, detailed learning outcomes for personal, interpersonal and product and system building skills, consistent with program goals and validated by program stakeholders			
3	Integrated Curriculum A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal and product and system building skills			
4	Introduction to Engineering An introductory course that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills			
5	Design-Build Experiences A curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level			
6	CDIO Workspaces Workspaces and laboratories that support and encourage hands-on learning of product and system building, disciplinary knowledge, and social learning			
7	Integrated Learning Experiences Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal and product and system building skills			
8	Active Learning Teaching and learning based on active, experiential learning methods			
9	Enhancement of Faculty CDIO Skills Actions that enhance faculty competence in personal, interpersonal and product and system building skills			
10	Enhancement of Faculty Teaching Skills Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning			
11	CDIO Skills Assessment Assessment of student learning in personal, interpersonal and product and system building skills, as well as in disciplinary knowledge			
12	CDIO Program Evaluation A system that evaluates programs against these twelve standards and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement			

Appendix 2: Accreditation conditions especially important in terms of CDIO (p. 5) [9]Quality assurance mechanisms:

- There is a quality assurance system with designated responsibility;
- This system includes the collection of information and the monitoring and periodic evaluation of the study cycle as well as the check of qualifications and competencies of the academic staff;
- The results of assessment are largely discussed and used to improve the quality of the study cycle;
- The quality assurance system has been certified.

Teaching objectives, curricular structure and syllabus

- There is a periodic mechanism for revision of the curricular structure to ensure that scientific updating of the study cycle and the work methodologies;
- The curricular structure is compatible with the Bologna process
- The objectives of the study cycle were implemented and are easily measured.

Organization of the curricular units

- There is an effective coordination between the curricular units and the contents in order to ensure their coherence with the defined objectives
- The objectives of each curricular unit are known by the academic staff and students;
- The competencies to be acquired in each curricular unit are defined.

Teaching/learning methodologies

- The teaching methodologies and the didactic techniques are adapted to the teaching objectives and facilitate the student participation in research;
- The average of the needed study time corresponds to the estimated (ECT);
- The student evaluation is made by considering the objectives of each curricular unit.

THE CDIO AS AN ENABLER FOR GRADUATE ATTRIBUTES ASSESSMENT IN CANADIAN ENGINEERING SCHOOLS

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ABSTRACT

Recent changes to the criteria for engineering accreditation in Canada emphasize continuous curriculum improvement through outcomes-based assessment. In this paper, we show how the CDIO approach not only enables continuous improvement, but can assist Canadian engineering programs with the overall graduate attributes assessment process.

Keywords – Accreditation, Graduate Attributes, Outcomes-based Assessment, CDIO Syllabus.

1. INTRODUCTION

In 2008, the CEAB (Canadian Engineering Accreditation Board) [1] updated their criteria and procedures [2], moving toward a model that emphasizes continuous improvement, and more specifically, program outcomes. Although outcomes-based assessment is a well-established component of many national engineering accreditation boards (e.g., ABET [3]), it is relatively new in the Canadian context. This is not to say that outcomes-based assessment is not practiced in Canada – other national accreditation boards (e.g., medicine) have been relying on outcomes-based assessment for years and many of our colleagues use it as part of their teaching and learning strategies – however, there is very little experience with outcomes-based assessment at the engineering programs level in Canada.

In this paper, we describe the process that is being followed at the Schulich School of Engineering to address the CEAB's new graduate attributes criterion (Figure 1), and show how the CDIO syllabus [4] can play an integral role in this process.

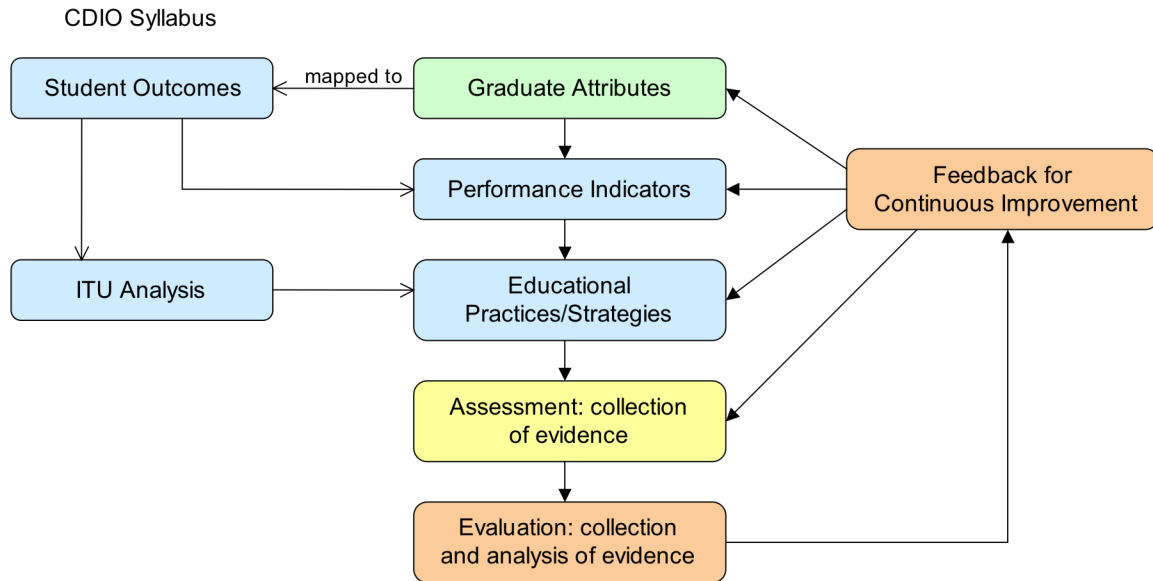


Figure 1. CEAB Graduate Attribute Planning and the CDIO Syllabus

The main advantage of this approach is that the CEAB's graduate attributes can be linked to the comprehensive CDIO syllabus [5]. More specifically, the CDIO syllabus can be viewed in the context of a typical program assessment planning flow chart [6] as follows:

CDIO Syllabus		Graduate Attributes Assessment
Level 1	⇔	Program Educational Objectives
Level 2	⇔	Student Outcomes / Graduate Attributes
Level 3	⇔	Performance Indicators

where "Level 1" refers to the first level of detail of the CDIO syllabus (e.g., "2 Personal and Professional Skills and Attributes") and "Level 2" and "Level 3" refer to the second and third level of detail respectively.

It should be noted that this approach does not discount the stakeholder engagement that is inherent to outcomes-based assessment. Instead, the CDIO syllabus is used as a starting point for program assessment and as a means of informing and focusing the discussions around program-specific outcomes and performance criteria. As illustrated in Figure 1, feedback is required at all stages of the process, involving input from educational researchers (e.g., assessment design, teaching and learning strategies), engineering educators (e.g., direct assessment, educational practices/strategies), engineering students (e.g., indirect assessment via self-efficacy surveys), and engineering employers (e.g., input on student outcomes, indirect assessment via surveys).

Although this addition to the CEAB accreditation requirements may at first appear onerous, if applied properly it can result in a positive environment for, and an enabler of

curriculum reform. In this paper, we build on our previous work on curriculum mapping [7] to show how the CDIO approach can facilitate this overall process.

The paper is divided into two main sections. First, we describe the graduate attributes assessment process that is currently being followed at the Schulich School of Engineering. This process is built on the typical program assessment planning flow chart [6], but relies heavily on the CDIO approach given the B.Sc. in Mechanical Engineering's link to CDIO. Next, we comment on the overall continuous improvement process that is tightly linked to every step in the graduate attributes assessment process. The paper concludes with a short summary and comments on the CDIO and CEAB graduate attributes assessment.

GRADUATE ATTRIBUTES ASSESSMENT PROCESS

This section provides an overview of the process that is being used at the Schulich School of Engineering for graduate attributes assessment. We start at the top of Figure 1 with broad program objectives / graduate attributes, and refine the process to the collection of evidence on individual performance indicators. In order to provide a more concrete example, we focus on only one of the Schulich School of Engineering's undergraduate programs: the B.Sc. in Mechanical Engineering program.

Program Educational Objectives and Student Outcomes

In the context of outcomes-based assessment, CEAB graduate attributes are very similar to student outcomes or program outcomes: e.g., ABET defines "student outcomes" as "what students are able to do by the time of graduation ... relate to the knowledge, skills, and behaviours that students acquire as they progress through the program" [3]. ABET encourages programs to establish their own student outcomes that are more reflective of their program's educational objectives, then map their program-specific outcomes to ABET's criteria.

This same process can be followed with respect to the CEAB's graduate attributes. More specifically, each program can develop its own set of student outcomes that are mapped directly to the CEAB graduate attributes as shown in Figure 1. Before looking at how this is done, it is useful to look at the relationship between "program educational objectives" and "student outcomes."

Like graduate attributes, student outcomes are focused on what students can do at the time of graduation. However, from an employer's perspective (e.g., industry, government, etc.), the interest is more in what graduates are expected to attain within a few years after graduation. These broader, "program educational objectives" are less in the program's control since our graduates' work and life experiences factor into these "outcomes." However, broad program educational objectives help to focus a program's more detailed student outcomes.

When starting from scratch, a department should consult with their constituents and stakeholders (e.g., industry, community, etc.) when developing their program educational objectives. As shown in Table 1, the CDIO syllabus can be used as a starting point for this work.

Table 1
The CDIO Syllabus and Program Educational Objectives

CDIO Syllabus (Level 1)		Mechanical Engineering Program Educational Objectives
1. Technical knowledge and reasoning	⇔	1. Demonstrate a deep working knowledge of technical fundamentals
2. Personal and Professional Skills and Attributes	⇔	2. Apply and master personal and professional skills and attributes
3. Interpersonal Skills: Teamwork and Communication	⇔	3. Communicate effectively and work in multidisciplinary teams
4. Conceiving, Designing, Implementing and Operating Systems in the Enterprise and Societal Context	⇔	4. Conceive, design, implement and operate systems in enterprise and social contexts

In this example, Level 1 of the CDIO syllabus is used as a starting point to develop more program-specific educational objectives for the Schulich School of Engineering's B.Sc. in Mechanical Engineering. As noted, these should be developed with the input of the program's constituents/stakeholders – however, the CDIO syllabus provides a good starting point for discussions.

In a similar manner, Level 2 of the CDIO Syllabus can now be used to describe how the program can be articulated in terms of program educational objectives and student outcomes. For example, as shown in Table 2, the second B.Sc. in Mechanical Engineering program educational objective “apply and master personal and professional skills and attributes” can be expanded into a set of program-specific student outcomes using Level 2 of the CDIO Syllabus.

Table 2
Student Outcomes for “Personal and Professional Skills and Attributes”

CDIO Syllabus (Level 2)		Mechanical Engineering Student Outcomes
2.1 - Engineering reasoning and problem solving	⇔	2.1 - Analyze and solve engineering problems
2.2 - Experimentation and knowledge discovery	⇔	2.2 - Conduct inquiry and experimentation in engineering problems
2.3 - System thinking	⇔	2.3 - Think holistically and systematically
2.4 - Personal skills and attitudes	⇔	2.4 - Master personal skills that contribute to successful engineering practice: initiative, flexibility, creativity, curiosity, and time management
2.5 - Professional skills and attitudes	⇔	2.5 - Master professional skills that contribute to successful engineering practice: professional ethics, integrity, currency in the field, career planning

As can be seen in Table 2, although the CDIO personal and professional skills and attributes have not been changed substantially to reflect those of the program, there is the opportunity to emphasize or de-emphasize topics at this stage to match the program's unique objectives.

Once the program has been described in terms of program educational objectives and student outcomes, the mapping between the CDIO Syllabus and the CEAB graduate attributes described by Cloutier et al. [5] can be applied. Figure 2 shows an example of this mapping for the B.Sc. in Mechanical Engineering program.

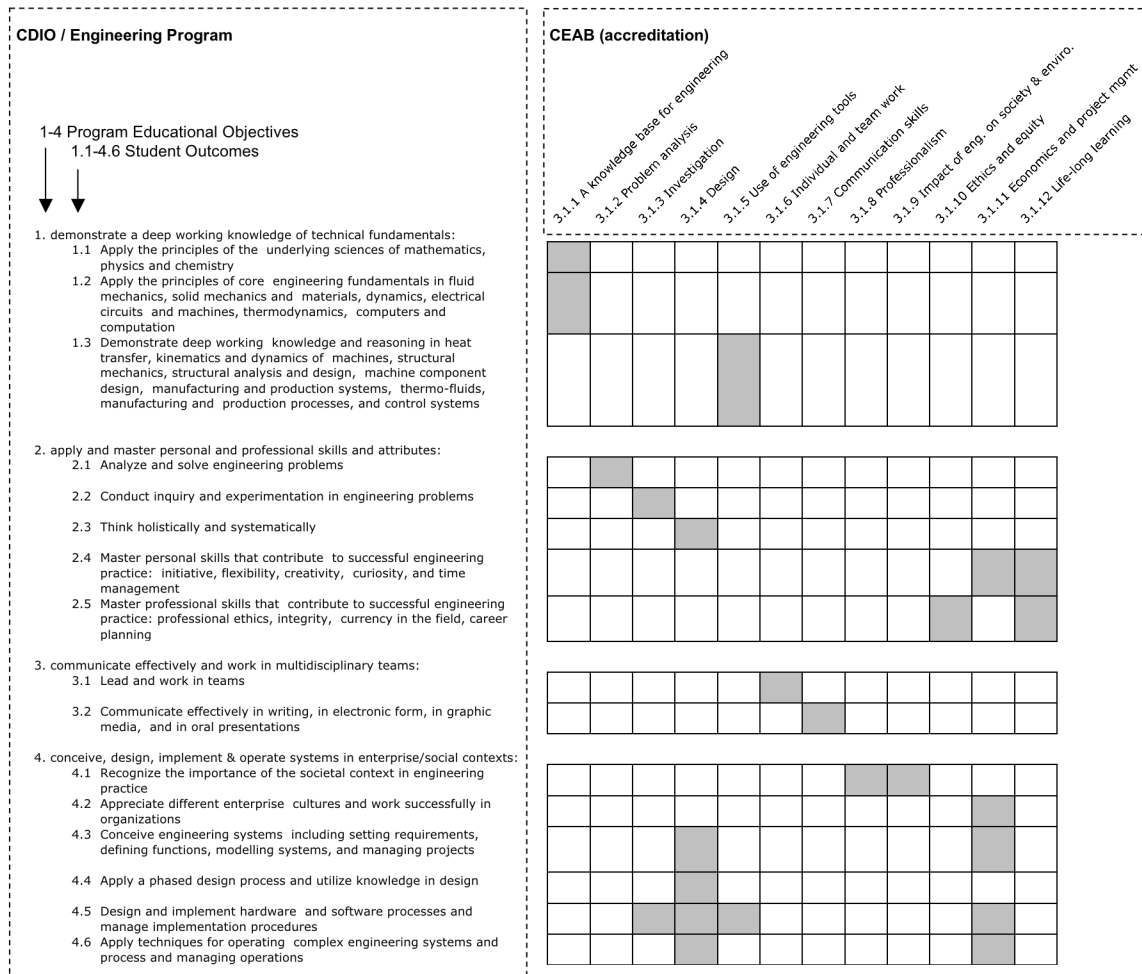


Figure 2. Student Outcomes / Graduate Attributes Mapping for the B.Sc. in Mechanical Engineering Program

The left side of Figure 2 describes educational objectives and student outcomes in the context of the engineering program (the B.Sc. in Mechanical Engineering program in this case) and the CDIO; the top right side of Figure 2 shows the engineering accreditation

board's requirements with respect to student outcomes (CEAB "graduate attributes" in this case); the Cloutier et al. [5] mapping is illustrated by the grey squares.

A quick inspection of Figure 2 may lead one to the conclusion that a considerable amount of work has been done, yet we are now only at the starting point. In other words, why not forego the work described to this point, and just jump to the CEAB graduate attributes?

The strength of the approach described so far is that it results in a set of student outcomes that are generated by the department, rather than a set of student outcomes that are imposed by an external (accreditation) body. As a result, the student outcomes will more closely reflect the unique character of the program, and – since stakeholder input is part of this process – there should be greater ownership with the process when the hard work of assessment and evaluation begins.

Given that the Schulich School of Engineering's B.Sc. in Mechanical Engineering program is a CDIO program, the department did not have to start from scratch to generate the student outcomes listed on the left side of Figure 2. Instead, the CDIO Syllabus could be used as a starting point for this work, informing decisions around what set of student outcomes best reflect the program.

Performance Indicators and Course Mapping

In the same way that Program Educational Objectives and Student Outcomes could be generated from Level 1 and Level 2 of the CDIO Syllabus respectively, Level 3 of the syllabus was used to help with the generation of performance indicators (i.e., intended learning outcomes for individual courses). Ideally, faculty members who have interest/expertise in specific student outcomes / graduate attributes should refine the Level 3 learning outcomes (i.e., performance indicators) at this point; however, even without this initial work, curriculum mapping (i.e., "educational practices and strategies" in Figure 1) can begin.

In a pilot study of the Schulich School of Engineering's B.Sc. in Mechanical Engineering program [7], the work by Cloutier et al. [5] was extended to determine where the CEAB's twelve graduate attributes are introduced, taught, and/or utilized throughout the program. More specifically, a full introduce-teach-utilize (ITU) analysis (e.g., [8,9]) of the mechanical engineering curriculum was performed via a survey of the instructors of Fall 2008 and Winter 2009 courses. The survey was conducted by a series of one-hour meetings with all faculty involved in delivering the mechanical engineering program and involved a series of questions of two types. First, the instructors used the CDIO syllabus to map learning activities and student outcomes. For each category, the instructor was asked if the activity was introduced (i.e., superficial treatment to briefly expose the topic), taught (i.e., detailed coverage with assignments / exams) or utilized (i.e., assume the student is already skilled in this area) in their course. Secondly, eight questions were asked that focused on determining the intended learning outcomes (i.e., performance indicators) of the course.

Figure 3 provides an example of this mapping for the CEAB graduate attribute "3.1.4 Design." In this case, we show only two (of thirteen) of the CDIO Level 3 topics that map

to this attribute as well as the associated course mapping generated from the ITU analysis [7].

3.1.4 Design: An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.				
CDIO Syllabus Topics	CDIO Learning Outcomes	Courses		
		Introduce	Teach	Utilize
4.3.1 Setting System Goals and Requirements	<ul style="list-style-type: none"> * Identify market needs and opportunities * Elicit and interpret customer needs * Identify opportunities that derive from new technology or latent needs * Explain factors that set the context of the requirements * Identify enterprise goals, strategies, capabilities and alliances * Locate and classify competitors and benchmarking information * Interpret ethical, social, environmental, legal and regulatory influences * Explain the probability of change in the factors that influence the system, its goals and resources available * Interpret system goals and requirements * Identify the language/format of goals and requirements * Identify initial target goals (based on needs, opportunities and other influences) * Explain system performance metrics * Interpret requirement completeness and consistency 		ENGG 200 ENGG 513 ENME 538	ENGG 200 ENME 538
4.3.2 Defining Function, Concept and Architecture	<ul style="list-style-type: none"> * Identify necessary system functions (and behavioral specifications) * Select system concepts * Identify the appropriate level of technology * Analyze trade-offs among and recombination of concepts * Identify high level architectural form and structure * Discuss the decomposition of form into elements, assignment of function to elements, and definition of interfaces 	ENGG 233	ENGG 200 ENME 538	ENGG 200 ENME 538

Figure 3. Example of a Curriculum Mapping for CEAB Graduate Attribute 3.1.4

Although it is tempting at this stage to simply use the “CDIO learning outcomes” as performance indicators and collect evidence in all of the courses where assessment occurs (i.e., courses where the topics are taught and/or utilized), it becomes clear very quickly that this process is not manageable. Given the detail of the CDIO Syllabus, this step results in a very large number of “CDIO learning outcomes”, mapped to a very large number of courses. For example, graduate attribute “3.1.4 Design” alone results in 63 CDIO learning outcomes mapped to 7 courses.

In order to make the process more manageable, the program’s teaching faculty were consulted to review the course mappings and help generate a (smaller) set of key performance indicators from the long list of CDIO learning outcomes that capture the most important aspects of teach of the CEAB’s graduate attributes. For example, the bold CDIO learning outcomes shown in Figure 3 were selected for the “3.1.4 Design” graduate attribute, resulting in the following performance indicators:

1. Elicit and interpret customer needs.

2. Interpret ethical, social, environmental, legal and regulatory influences.
3. Identify and explain system performance metrics.
4. Select concepts and analyze the trade-offs among and recombination of alternative concepts.
5. Decompose and assign function to elements, and define interfaces.
6. Use prototypes and test articles in design development.
7. Demonstrate iteration until convergence and synthesize the final design.
8. Demonstrate accommodation of changing requirements.

Given that the performance indicators were generated in collaboration with the teaching faculty, it also became apparent where the direct assessments should occur. For example, for the Design graduate attribute, the first-year design and communication course (ENGG 200 in Figure 3) appeared to be the best source for formative assessments, while the final-year capstone design course (ENME 538 in Figure 3) appeared to be the best source for summative assessments.

Collection of Evidence

The “assessment: collection of evidence” stage of the process shown in Figure 1 involves both the identification of forms of evidence of student learning, and the establishment of levels of student achievement. The basis for this work is the performance indicators discussed previously: i.e., evidence should be collected on each performance indicator.

At this stage of the process, specific courses are identified for direct assessment (using the curriculum maps described previously), and decisions are made about the forms of indirect assessment that will be used. It is best to identify at least two or three forms of evidence for each of the performance indicators in order to ensure that the results are aligned, and if not, to provide feedback to refine the measures (i.e., triangulation of results).

Typically, a sampling approach is used at this stage of the process. For example, a representative sample of graduating students can be given exit interviews in their final year of study, an alumni survey can be used provided that enough responses are received to reach conclusions about the results (e.g., 90% confidence interval), and in-class, summative assessments can be given to classes with representative numbers of students within a cohort (e.g., a project report in a core course).

Although, as discussed previously, the number of potential performance indicators was reduced to a more manageable set of key performance indicators, the number of assessments is still quite large: i.e., for each of the twelve graduate attributes, at least three forms of evidence must be collected on approximately five to eight performance indicators. To enable an ongoing graduate attribute assessment process that is reasonable and manageable, the Schulich School of Engineering chose to follow a multi-year data collection plan, shown in Figure 4.

CEAB Graduate Attribute Data Collection Plan						
Graduate Attribute	Academic Year					
	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16
3.1.1 A knowledge base for engineering						
3.1.2 Problem analysis						
3.1.3 Investigation						
3.1.4 Design						
3.1.5 Use of engineering tools						
3.1.6 Individual and team work						
3.1.7 Communication skills						
3.1.8 Professionalism						
3.1.9 Impact of engineering on society and environment						
3.1.10 Ethics and equity						
3.1.11 Economics and project management						
3.1.12 Life-long learning						
Notes:						
1.		= direct assessment in courses (ENGG 200, ENGG 481, and capstone) and indirect assessment via surveys				
2.		= indirect assessment via surveys				

Figure 4. CEAB Graduate Attribute Data Collection Plan

This plan involves collecting data on four graduate attributes per year and results in two to three assessments of each of the CEAB graduate attributes by the next (and every subsequent) accreditation cycle. Table 3 on the next page provides an example of the graduate attribute assessment plans for four (of the eight) performance indicators used for CEAB graduate attribute 3.1.4.

CONTINUOUS IMPROVEMENT

As noted at the start of this paper, the overall purpose of graduate attribute assessment is to establish a process for the continuous improvement of each program's curriculum. However, as shown in Figure 1 and implied throughout this document, feedback for continuous improvement occurs at all stages of the process. In the remainder of this section, we summarize our thoughts on how continuous improvement can occur in the context of the process described in this section.

Performance Indicators and Educational Practices/Strategies

It is hoped that our initial efforts to establish meaningful and measurable performance indicators are successful. The real test of our efforts will occur when they are put to use. For example, faculty will need to work with their department's program assessment person (people) to develop forms of evidence: this work should provide feedback on the performance indicator (e.g., if it makes sense, can be assessed, etc.) and the course mapping (e.g., is this really an outcome of the course?). Similarly, indirect evidence like

surveys will require some fine-tuning (e.g., rephrasing of ambiguous or leading questions).

As well, given that our focus is on a relatively small set of “key performance indicators”, it is important to ask if the correct performance indicators were defined: are they representative of the graduate attribute? are new performance indicators required? should some performance indicators be removed?

Table 3. An Example of an Assessment Plan for Graduate Attribute 3.1.4 “Design”

Graduate Attribute: 3.1.4 Design						
Performance Indicators	Courses	Method(s) of Assessment	Source of Assessment	Time of Data Collection	Assessment Coordinator	Evaluation of Results
1. Elicit and interpret customer needs.	ENGG200, ENGG513, ENME538, ENME585	Faculty evaluations	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	Engineering Undergraduate Studies Committee
		Student surveys	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	
		Alumni surveys	Online survey	Winter	2011 – R. Brennan 2014 – R. Brennan	
2. Interpret ethical, social, environmental, legal and regulatory influences.	ENGG200, ENGG513, ENME538, ENME585	Faculty evaluations	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	Engineering Undergraduate Studies Committee
		Student surveys	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	
		Alumni surveys	Online survey	Winter	2011 – R. Brennan 2014 – R. Brennan	
3. Identify and explain system performance metrics.	ENGG200, ENGG513, ENME538, ENME585	Faculty evaluations	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	Engineering Undergraduate Studies Committee
		Student surveys	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	
		Alumni surveys	Online survey	Winter	2011 – R. Brennan 2014 – R. Brennan	
4. Select concepts and analyze the trade-offs among and recombination of alternative concepts	ENGG200, ENME337, ENME473, ENME493, ENME538, ENME585	Faculty evaluations	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	Engineering Undergraduate Studies Committee
		Student surveys	ENGG200 & ENME538	Fall & Winter	2010 – W. Rosehart 2011 – R. Hugo	
		Alumni surveys	Online survey	Winter	2011 – R. Brennan 2014 – R. Brennan	

Collection of Evidence

Although the purpose of collecting evidence is to assess the program’s graduates in the context of the graduate attributes, a considerable amount of information should also be available on the assessment process itself. For example:

- Forms of Evidence: Are the assessments appropriate (e.g., is a term test, a report, etc. the best way to assess the attribute)? Is the timing of the assessment appropriate (e.g., should the alumni survey be done during the Winter term)?
- Performance Targets: Do the performance targets need to be adjusted up or down?
- Triangulation: Are the various forms of evidence arriving at the same results?
- Number of Samples: Did we sample enough students/alumni/industry?

Curriculum

As noted, the information that is obtained from the graduate attributes assessment process should be used to inform discussions and actions about program's curriculum at various levels. Individual faculty members as well as department curriculum committee representatives should ask themselves what the results are telling them about:

- Course Design: the emphasis in lectures and/or labs may be misaligned with the courses' learning objectives; the assessments may be inappropriate (e.g., should ethics be assessed with a multiple choice exam?); the course may assume that students have prerequisite knowledge that they do not have; etc.
- Program Design: the course sequence may be incorrect; important program outcomes may be missed or underemphasized in the program; etc.
- Common Core Design: similar questions to "program design", but from a shared, faculty-wide perspective.

Data vs. Information

Finally, it is important to emphasize that the graduate attribute assessment process is intended to provide engineering programs with information that can be used to fine-tune the process and improve their undergraduate programs. There is always the temptation to collect as much data as possible, then cross one's fingers and hope that something can be learned. However, if the process is carefully planned from the start, and feedback is used to refine the process, we should be able to reach the point where all of our graduate attributes assessment efforts are meaningful (and manageable).

SUMMARY

Programs do not have to adopt the "CDIO Approach" [4] to take advantage of the CDIO syllabus for graduate attributes assessment. As noted, the CDIO syllabus is effectively a very detailed list of general engineering program outcomes that should apply to any engineering discipline. The advantage to the approach described in this paper is that the considerable amount of work that has been accomplished by an international community of engineering educators can be used as a starting point for a program's work on graduate attributes assessment.

To achieve an effective continuous improvement process though, it is still very important to engage faculty, students, and other stakeholders in the process to build on the CDIO work and thereby make the process specific to the School's individual programs.

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MAPPING THE RELATIONSHIP BETWEEN THE CDIO SYLLABUS AND THE CEAB GRADUATE ATTRIBUTES: AN UPDATE

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ABSTRACT

The recently introduced Canadian Engineering Accreditation Board (CEAB) requirements for Graduate Attributes [1] require demonstrated learning outcomes for the first time. CDIO has required outcomes and benchmarking for more than a decade, and the CDIO Syllabus [2] has provided a detailed and proven framework within which to organize the topics covered by those outcomes. The latest revision of the syllabus informs many of our programs, and can provide the detail on how we can document a set of outcomes that meet the more general requirements of the CEAB Graduate Attributes. This paper provides a framework for Canadian engineering programs to satisfy CEAB requirements through a mapping of the CDIO Syllabus topics to the CEAB Attributes, and verification of the completeness of that list. An engineering program can meet all of the CEAB Graduate Attribute requirements by addressing a subset of the CDIO Syllabus, however a CEAB accredited program may not meet all of the requirements of CDIO.

KEYWORDS

CEAB, Graduate Attributes, curriculum mapping, program assessment

INTRODUCTION

CDIO Standard 2 stipulates learning outcomes based on a syllabus that has been validated by program stakeholders and most CDIO programs have used the CDIO Syllabus (version 1) [2] as the basis for developing their own outcomes. Version 2.30 of the Syllabus was presented in draft form at the 2010 CDIO International Conference and approved by CDIO International Council in December 2010. This updated paper repeats much of the content of the original [3] for completeness and incorporates the changes adopted in version 2.30 of the syllabus.

CDIO is not the only initiative in engineering education developing outcomes based approaches and most national and international accreditation organizations are moving towards approaches that are compatible with the CDIO Syllabus. The Canadian Engineering Accreditation Board published new guidelines in 2008 [1], including a set of attributes specifying general program outcomes for the first time, while still retaining criteria based on

instructional hours and content. Section 3.1 of the document specifies a set of twelve "Graduate Attributes" that all students should have on completion of an accredited program in engineering. They are:

- | | |
|--|---|
| 3.1.1 A knowledge base for engineering | 3.1.7 Communication Skills |
| 3.1.2 Problem analysis | 3.1.8 Professionalism |
| 3.1.3 Investigation | 3.1.9 Impact of engineering on
society and the environment |
| 3.1.4 Design | 3.1.10 Ethics and equity |
| 3.1.5 Use of engineering tools | 3.1.11 Economics and project management |
| 3.1.6 Individual and team work | 3.1.12 Life-long learning |

All of them elaborate on "demonstrated competence," "an ability," or "an understanding" without detailing the level to be attained in each particular aspect. This leaves room for individual institutions to establish their own priorities among the attributes as long as all are adequately addressed, usually within the context of complex problems.

Under the International Engineering Alliance (IEA), various international agreements govern mutual recognition of engineering qualifications and professional competence, by the recognition of substantial equivalence in the accreditation of qualifications : the *Washington Accord* (1989) in professional engineering, co-signed by Engineers Canada; the *Sydney Accord* (2001) in engineering technology and the *Dublin Accord* (2002) in technician engineering, both co-signed by the Canadian Council of Technicians and Technologists. In June 2009, the Japanese Accreditation Board for Engineering Education and the Institution of Engineers Japan hosted the Kyoto meeting. The ensuing meeting paper [4] describes graduate attributes and professional competencies. It also formally defines terms like *complex problem* and *simple to complex activities* used in the CEAB documents. The IEA paper details 12 *graduate attributes*: "components indicative of the graduate's potential to acquire competence to practise at the appropriate level," which the CEAB uses explicitly to honour their commitment to the Washington Accord. The paper also defines 13 professional competencies require for one to "demonstrate that he/she is able to practice competently in his/her practice area to the standard expected of a reasonable Professional Engineer."

OBJECTIVES

There is broad consensus on directions in engineering education that are consistent with CDIO objectives. This comparison aims to show that the new CEAB Graduate Attributes are consistent with and complementary to the CDIO Syllabus. Version 2.30 of the CDIO Syllabus groups topics in four primary areas, 1 – 4 which subdivide into 19 major topics at the second level, 1.1 – 4.8, at a level of detail comparable to the CEAB attributes.

In this era of accountability, most engineering departments face multiple tests against different standards to verify program quality on various bases. We would all benefit if the process of documentation could be streamlined. The very practical objective of this work is to show how a properly documented CDIO program can meet all of the new CEAB graduate attribute requirements; that CDIO is a superset of those requirements.

PROCESS

The authors met and discussed at length the correlation between the 12 attributes and 19 topics, sometimes with reference to background at lower levels of detail. This process convinced us there was merit in the idea and resulted in the table of correlations shown in table 1. Although satisfying, this table does not go beyond summarizing apparent correlations between areas. At this level of detail it is not possible to validate requirements in either direction.

The CEAB attributes are sufficiently general that it is not possible to map them directly to individual level 3 or 4 CDIO syllabus topics. A graduate might have the CEAB attribute

“3.1.12 Life-long learning: An ability to identify and to address their own educational needs in a changing world, sufficiently to maintain their competence and contribute to the advancement of knowledge” without addressing CDIO topic “2.5.3 Proactive Vision and Intention in Life.” Yet, addressing topic 2.5.3 is certainly a contribution towards meeting attribute 3.1.12.

The practical objective of showing a CDIO program meets CEAB attributes requires a mapping of syllabus topics to attributes, recognizing that while many topics may contribute to an attribute, only some will be absolutely essential to that attribute. Accordingly, we reviewed each of the topics for potential contributions to the attributes, and ranked them with values from 0 (very little contribution) to 1 (very strong contribution). The basis for the rankings was our expectation that a deliverable or an activity associated with a particular syllabus topic would contain evidence of a student’s possession of a particular attribute. These values are indications of where one should look for evidence of performance in auditing individual students or a program.

In completing this assessment, we recognized that some elements are essential in the demonstration of many of the attributes. For example, it is hard to imagine how one would demonstrate engineering problem solving in the absence of an engineering knowledge base. Rather than link a particular topic to many or all attributes, we only linked those topics that would provide additional evidence for a particular attribute that may not have been relevant to an earlier numbered attribute.

We then tested our list for completeness, assessing which of those syllabus topics were required as part of a particular attribute, and whether that list of required topics was sufficient to cover all aspects of an attribute. The standard for inclusion was “Must all graduates of an engineering program address this topic to show they have this attribute?” These *must have* topics are identified in the tables in a larger font and bold type and shaded in red.

No attempt was made to define the level of proficiency needed in each topic area, as this aspect requires extensive input from stakeholders. We also felt that assessment of whether the collection of deliverables and activities met the requirements of the attributes for “complexity” could only be addressed in the context of an overall program, rather than topic by topic.

RESULTS

The 12 by 19 matrix in table 1 provides a summary that clearly shows the correlation between the CDIO Syllabus and the CEAB Graduate Attributes. This strong agreement in general terms is born out by the detailed analysis.

Table 2 provides a more detailed look at how the over 100 topics in the CDIO Syllabus at the third level of detail can combine to satisfy the CEAB Attributes. The CDIO Syllabus also contains a fourth level of detail with hundreds of individual topics identified. Level four topics are of great value in selecting assessment activities once the level of proficiency is chosen. The matching of topics is detailed attribute by attribute in the paragraphs that follow, with some reference to the fourth level of CDIO detail where required. The quoted text is the full description of each attribute from the CEAB document.

One outcome that arises is the identification of some critical elements that are implicit in the CEAB Attributes while being explicitly identified in the CDIO Syllabus. System Thinking and Critical Thinking show up as syllabus topics that should be in evidence to adequately address many of the attributes. Likewise there are several attributes, Engineering Tools, Impact on Society, and Economics, that include elements identified explicitly in multiple different subsections of the syllabus.

Version 2.30 of the CDIO Syllabus includes optional topics 4.7 Leading Engineering Endeavors and 4.8 Entrepreneurship and their third level subtopics. These topics were

clearly recognized by CDIO Council as optional specializations in leadership and entrepreneurship skills that go beyond the basic skills required for all engineering graduates. While 4.7.x and 4.8.x can contribute to some of the CEAB Graduate Attributes, they are not required to meet any of them.

Table 1
Overview of correlations between the CDIO Syllabus and CEAB Graduate Attributes

CEAB Graduate Attributes		3.1.1	3.1.2	3.1.3	3.1.4	3.1.5	3.1.6	3.1.7	3.1.8	3.1.9	3.1.10	3.1.11	3.1.12
Matrix entries are between 0 and 1 for the extent that a given CDIO syllabus element may contribute to satisfying requirements for a given CEAB attribute (green). Large, bold entries indicate topics required to meet an attribute (red).		A knowledge base for engineering	Problem Analysis	Investigation	Design	Use of engineering tools	Individual and team work	Communication skills	Professionalism	Impact of engineering on society	Ethics and equity	Economics and project management	Life-long learning
CDIO Syllabus version 2.30 [ABET a-k]													
1	DISCIPLINARY KNOWLEDGE AND REASONING												
1.1	KNOWLEDGE OF UNDERLYING MATHEMATICS AND SCIENCES [a]	1.00											
1.2	CORE FUNDAMENTAL KNOWLEDGE OF ENGINEERING [a]	1.00											
1.3	ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, METHODS AND TOOLS [k]	0.50				1.00							
2	PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES												
2.1	ANALYTICAL REASONING AND PROBLEM SOLVING [e]		1.00			0.25						0.50	
2.2	EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY [b]			1.00		0.25		0.50					
2.3	SYSTEM THINKING		0.50		0.50	0.25				0.50		0.25	
2.4	ATTITUDES, THOUGHT AND LEARNING		1.00	1.00	1.00	1.00	0.50			0.25		0.25	1.00
2.5	ETHICS, EQUITY AND OTHER RESPONSIBILITIES						0.25		1.00	0.25	1.00		0.50
3	INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION												
3.1	TEAMWORK [d]						1.00						
3.2	COMMUNICATIONS [g]						0.25	1.00					0.25
3.3	COMMUNICATIONS IN A FOREIGN LANGUAGE							0.25					
4	CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE PROCESS OF INNOVATION												
4.1	EXTERNAL, SOCIETAL, AND ENVIRONMENTAL CONTEXT [h]								1.00	1.00	0.50		0.25
4.2	ENTERPRISE AND BUSINESS CONTEXT					0.25	0.50					1.00	
4.3	CONCEIVING, SYSTEMS ENGINEERING AND MANAGEMENT [c]				1.00	0.25				0.50		0.50	
4.4	DESIGNING [c]				1.00	0.25				0.50		0.25	
4.5	IMPLEMENTING [c]				0.50	0.50				0.50		0.50	
4.6	OPERATING [c]				0.50	0.50	0.25			0.50		0.25	
4.7	LEADING ENGINEERING ENDEAVORS				0.50		1.00	0.50				0.50	
4.8	ENTREPRENEURSHIP				0.50		1.00	0.50				1.00	

“3.1.1 A knowledge base for engineering: Demonstrated competence in university level mathematics, natural sciences, engineering fundamentals, and specialized engineering knowledge appropriate to the program.”

A knowledge base is clearly to be understood as a *working* knowledge base at the course level. Without wandering into subtle discussions about what deserves to be called a “problem,” we understood attribute 3.1.1 dealt more with working knowledge at the applied-knowledge-acquisition “exercise” levels, whereas attribute 3.1.2 introduced “problems” and complexity.

Underlying mathematics and science is the natural mandatory stepping stone of applied knowledge. Note this has no bearing on the pedagogical approach used, and bears no implicit conclusion about a “theory first, applications later” preference.

CDIO 1.2 “Core *Fundamental* Knowledge of Engineering” — however we detail it — is the essence of a knowledge base for engineering “appropriate to the program.” Topic 1.3 “Advanced Engineering Fundamental Knowledge, Methods and Tools” has to be an essential complement, even if there is a rationale to associate it also to the CEAB 3.1.5 attribute, as illustrated within the list following.

As CDIO 2 and 3 cover skills, and all CDIO 4 sub-topics dealt with increased complexity and open-ended problems with multiple criteria, it was felt only the CDIO 1.x topics suitably matched the CEAB 3.1.1 attribute at the knowledge acquisition “exercise” level.

Table 2 (a)
Detailed mapping of CDIO Syllabus topics 1.X.X – 3.X.X contributions to meeting the CEAB Graduate Attribute requirements

CEAB Graduate Attributes		3.1.1	3.1.2	3.1.3	3.1.4	3.1.5	3.1.6	3.1.7	3.1.8	3.1.9	3.1.10	3.1.11	3.1.12
Matrix entries are between 0 and 1 for the extent that a given CDIO syllabus element may contribute to satisfying requirements for a given CEAB attribute (green). Large, bold entries indicate topics required to meet an attribute (red).		A knowledge base for engineering	Problem Analysis	Investigation	Design	Use of engineering tools	Individual and team work	Communication skills	Professionalism	Impact of engineering on society	Ethics and equity	Economics and project management	Life-long learning
CDIO Syllabus version 2.30 [ABET a-k]													
1	DISCIPLINARY KNOWLEDGE AND REASONING												
1.1	KNOWLEDGE OF UNDERLYING MATHEMATICS AND SCIENCES [a]	1.00											
1.2	CORE FUNDAMENTAL KNOWLEDGE OF ENGINEERING [a]	1.00											
1.3	ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, METHODS AND TOOLS [k]	0.50				1.00							
2	PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES												
2.1	ANALYTICAL REASONING AND PROBLEM SOLVING [e]		1.00			0.25						0.50	
2.1.1	Problem Identification and Formulation		1.00										
2.1.2	Modeling		1.00			0.50							
2.1.3	Estimation and Qualitative Analysis		1.00										
2.1.4	Analysis With Uncertainty		1.00									0.50	
2.1.5	Solution and Recommendation		1.00			0.50							
2.2	EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY [b]			1.00		0.25		0.50					
2.2.1	Hypothesis Formulation			1.00									
2.2.2	Survey of Print and Electronic Literature			1.00				0.50					
2.2.3	Experimental Inquiry			1.00		0.50							
2.2.4	Hypothesis Test, and Defense			1.00									
2.3	SYSTEM THINKING		0.50		0.50	0.25				0.50		0.25	
2.3.1	Thinking Holistically		0.50		0.50	0.25				0.50		0.25	
2.3.2	Emergence and Interactions in Systems		0.50		0.50	0.25				0.50		0.25	
2.3.3	Prioritization and Focus		0.50		0.50	0.25				0.50		0.25	
2.3.4	Trade-offs, Judgment and Balance in Resolution		0.50		0.50	0.25				0.50		0.25	
2.4	ATTITUDES, THOUGHT AND LEARNING		1.00	1.00	1.00	1.00	0.50			0.25		0.25	1.00
2.4.1	Initiative and the Willingness to Make Decisions in the Face of Uncertainty						0.25			0.50		0.25	
2.4.2	Perseverance, Urgency and Will to Deliver, Resourcefulness and Flexibility						0.50					0.25	
2.4.3	Creative Thinking			1.00									
2.4.4	Critical Thinking		1.00	1.00	1.00	1.00						0.25	
2.4.5	Self-awareness, Meta-cognition and Knowledge Integration						0.50						1.00
2.4.6	Lifelong Learning and Educating [l]						0.25						1.00
2.4.7	Time and Resource Management						1.00					0.25	
2.5	ETHICS, EQUITY AND OTHER RESPONSIBILITIES						0.25		1.00	0.25	1.00		0.50
2.5.1	Ethics, Integrity and Social Responsibility [f]								1.00		1.00		
2.5.2	Professional Behavior [f]						0.50		0.50		1.00		
2.5.3	Proactive Vision and Intention in Life												0.50
2.5.4	Staying Current on the World of Engineering												0.50
2.5.5	Equity and Diversity									0.50	1.00		
2.5.6	Trust and Loyalty						0.50				0.50		
3	INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION												
3.1	TEAMWORK [d]						1.00						
3.1.1	Forming Effective Teams						1.00						
3.1.2	Team Operation						1.00						
3.1.3	Team Growth and Evolution						1.00						
3.1.4	Leadership						1.00						
3.1.5	Technical and Multi-disciplinary Teaming						1.00						
3.2	COMMUNICATIONS [g]					0.25		1.00					0.25
3.2.1	Communications Strategy							1.00					
3.2.2	Communications Structure							1.00					
3.2.3	Written Communication							1.00					
3.2.4	Electronic/Multimedia Communication							1.00					
3.2.5	Graphical Communication							1.00					
3.2.6	Oral Presentation							1.00					
3.2.7	Inquiry, Listening and Dialog					0.25		1.00					
3.2.8	Negotiation, Compromise and Conflict Resolution					0.25		0.25					
3.2.9	Advocacy					0.25		0.25					
3.2.10	Establishing Diverse Connections, Networking					0.25		0.25					0.25
3.3	COMMUNICATIONS IN A FOREIGN LANGUAGE							0.25					
3.3.1	Communications in English							0.25					
3.3.2	Communications in Languages of Regional Nations							0.25					
3.3.3	Communications in Other Languages							0.25					

“3.1.2 Problem analysis: An ability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems in order to reach substantiated conclusions.”

Problem analysis incorporates the production of conclusions, but not necessarily of “solutions” in the sense a design would. CDIO 2.1 “Analytical Reasoning and Problem Solving” is a natural match, down to detail levels 3 and 4 of the topics, bearing in mind the two level 4 sub-topics Problem solution and Summary recommendations are understood as “conclusions” rather than as a “design to successfully address the problem.” Sufficient complexity must be provided. Complexity modulation is achieved by a combination of conflicting requirements, depth of analysis, (un)familiarity of issues, consequences, and system interdependence. It is thus natural for CDIO 2.3 “System Thinking” to contribute and

2.4.4 “Critical Thinking” to be absolutely necessary to reach (and present) “substantiated conclusions.”

“3.1.3 Investigation: An ability to conduct investigations of complex problems by methods that include appropriate experiments, analysis and interpretation of data, and synthesis of information in order to reach valid conclusions.”

Investigation requires experiments, analysis of data, and synthesis of information. CDIO 2.1.3 and 2.1.4 are obvious *must have* matches which are presumed by satisfying CEAB 3.1.2. CDIO 2.4.4 “Critical Thinking” is explicitly required to address new aspects not evident in 3.1.2. All of the topics of CDIO 2.2 are *must have* on the basis of a direct match.

Table 2 (b)
Detailed mapping of CDIO Syllabus topics 4.X.X contributions to meeting the CEAB Graduate Attribute requirements

CEAB Graduate Attributes		3.1.1	3.1.2	3.1.3	3.1.4	3.1.5	3.1.6	3.1.7	3.1.8	3.1.9	3.1.10	3.1.11	3.1.12
Matrix entries are between 0 and 1 for the extent that a given CDIO syllabus element may contribute to satisfying requirements for a given CEAB attribute (green). Large, bold entries indicate topics required to meet an attribute (red).		A knowledge base for engineering	Problem Analysis	Investigation	Design	Use of engineering tools	Individual and team work	Communication skills	Professionalism	Impact of engineering on society	Ethics and equity	Economics and project management	Life-long learning
4	CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE PROCESS OF INNOVATION												
4.1	EXTERNAL, SOCIETAL, AND ENVIRONMENTAL CONTEXT [h]								1.00	1.00	0.50		0.25
4.1.1	Roles and Responsibility of Engineers								1.00	1.00	0.50		
4.1.2	The Impact of Engineering on Society and the Environment								0.25	1.00			
4.1.3	Society's Regulation of Engineering								1.00	1.00	0.50		
4.1.4	The Historical and Cultural Context								0.25	1.00			
4.1.5	Contemporary Issues and Values [i]								0.25	0.50	0.50		
4.1.6	Developing a Global Perspective								0.25	0.50			0.50
4.1.7	Sustainability and the Need for Sustainable Development								0.25	0.50			
4.2	ENTERPRISE AND BUSINESS CONTEXT				0.25	0.50						1.00	
4.2.1	Appreciating Different Enterprise Cultures					0.25						0.50	
4.2.2	Enterprise Stakeholders, Strategy and Goals					0.25						0.50	
4.2.3	Technical Entrepreneurship											0.50	
4.2.4	Working in Organizations						1.00						
4.2.5	Working in International Organizations						0.25						
4.2.6	New Technology Development and Assessment						0.25					0.25	
4.2.7	Engineering Project Finance and Economics					0.25						1.00	
4.3	CONCEIVING, SYSTEMS ENGINEERING AND MANAGEMENT [c]				1.00	0.25				0.50		0.50	
4.3.1	Understanding Needs and Setting Goals				1.00					0.50		0.50	
4.3.2	Defining Function, Concept and Architecture				1.00								
4.3.3	System Engineering - System Modeling and Interfaces				1.00	0.50							0.25
4.3.4	Development Project Management						0.25					1.00	
4.4	DESIGNING [c]				1.00	0.25				0.50		0.25	
4.4.1	The Design Process				1.00								
4.4.2	The Design Process Phasing and Approaches				1.00								
4.4.3	Utilization of Knowledge in Design				1.00	0.25							
4.4.4	Disciplinary Design				1.00	0.25							
4.4.5	Multidisciplinary Design				0.50	0.25							
4.4.6	Design for Sustainability, Safety, Operability, Aesthetics and other Objectives				0.50					1.00		0.25	
4.5	IMPLEMENTING [c]				0.50	0.50				0.50		0.50	
4.5.1	Designing a Sustainable Implementation Process				0.50					1.00		0.50	
4.5.2	Hardware Manufacturing Process					0.25							
4.5.3	Software Implementation Process					0.25							
4.5.4	Hardware Software Integration												
4.5.5	Test, Verification, Validation, and Certification					0.50						0.50	
4.5.6	Implementation Management						0.25					0.50	
4.6	OPERATING [c]				0.50	0.50	0.25			0.50		0.25	
4.6.1	Designing and Optimizing Sustainable and Safe Operations				0.50					1.00			
4.6.2	Training and Operations				0.50		0.25			0.50			
4.6.3	Supporting the System Lifecycle					0.25				1.00		0.25	
4.6.4	System Improvement and Evolution				0.50	0.25							
4.6.5	Disposal and Life-End Issues				0.50					0.50			
4.6.6	Operations Management				0.50	0.25	0.25						
4.7	LEADING ENGINEERING ENDEAVORS				0.50		1.00	0.50				0.50	
4.7.1	Thinking Creatively and Communicating Possibilities				0.50			0.50					
4.7.2	Defining the Solution				0.50								
4.7.3	Creating New Solution Concepts				0.50								
4.7.4	Building and Leading an Organization and Extended Organization						1.00						
4.7.5	Planning and Managing a Project to Completion											1.00	
4.7.6	Exercising Project/Solution Judgment				0.50							0.50	
4.7.7	Innovation – the Conception, Design and Introduction of New Goods and Services				0.50							0.50	
4.7.8	Invention – the Development of New Devices, Materials or Processes that Enable New Goods and Services				1.00								
4.7.9	Implementation and Operation – the Creation and Operation of the Goods and Services that will Deliver Value											0.50	
4.8	ENTREPRENEURSHIP				0.50		1.00	0.50				1.00	
4.8.1	Company Founding, Formulation, Leadership and Organization						1.00	0.50					
4.8.2	Business Plan Development											1.00	
4.8.3	Company Capitalization and Finances											1.00	
4.8.4	Innovative Product Marketing							0.50				0.25	
4.8.5	Conceiving Products and Services around New Technologies				0.50							0.50	
4.8.6	The Innovation System, Networks, Infrastructure and Services						0.50					0.50	
4.8.7	Building the Team and Initiating Engineering Processes						1.00						
4.8.8	Managing Intellectual Property				0.50							0.50	

“3.1.4 Design: An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations.”

This attribute requires a broad base in system, creative, and critical thinking skills, all necessary but insufficient without their application within the level 4 elements of CDIO 4.4.3 “Utilization of Knowledge in Design”.

Bearing in mind the responsibilities of engineers towards safe operation of their work, CDIO 4.6.1 is an essential element across all engineering specialties.

The first three elements of CDIO 4.3 directly address CEAB 3.1.4. CDIO 4.3.4 deals more with design project management, and the characteristics of “economic, environmental, cultural and societal considerations” were the ones more relevant to the design itself under CEAB 3.1.4. It is thus within the design goals, criteria and constraints definition within disciplinary design that a program will address these concerns. Although CDIO 4.4.5 and 4.4.6 are strong contributors, they are not essential elements in all engineering specialties, however each program should provide contributions from some of the CDIO level 4 topics as part of its distinctive character.

“3.1.5 Use of engineering tools: An ability to create, select, apply, and extend appropriate techniques, resources, and modern engineering tools to a range of engineering activities, from simple to complex, with an understanding of the associated limitations.”

CDIO 1.3 “Advanced Engineering Fundamental Knowledge, Methods and Tools” is a natural fit as *must have*, especially as it pertains to the methods and tools component. The statement “with an understanding of the associated limitations” also requires CDIO 2.4.4 “Critical Thinking,” a topic that is ubiquitous to many of the CEAB attributes. Although CDIO 2.1.2 “Modeling” does fit within this attribute, it has already been met with CEAB 3.1.2 and consequently it is a contributor, but not a *must have* and there are numerous topic areas where tools may be used.

“3.1.6 Individual and team work: An ability to work effectively as a member and leader in teams, preferably in a multi-disciplinary setting.”

The *must have* topics are under CDIO 3.1 “Teamwork,” specifically CDIO 3.1.1 “Forming Effective Teams,” 3.1.2 “Team Operation,” and 3.1.4 “Team Leadership.” The latter topic on team leadership was included given that CEAB Attribute 3.1.6 explicitly mentions “work effectively as a ... leader.” Contributions could also be evident in 3.1.3 “Team Growth and Evolution” which is good to see within a team environment, but not strictly required for functioning. CEAB mentions a preference for multidisciplinary teams, but not a requirement, thus 3.1.5 “Technical and Multi-disciplinary Teaming” could be a strong contributor without being a *must have*.

“3.1.7 Communication skills: An ability to communicate complex engineering concepts within the profession and with society at large. Such ability includes reading, writing, speaking and listening, and the ability to comprehend and write effective reports and design documentation, and to give and effectively respond to clear instructions.”

CDIO 2.2.2. “Survey of Print and Electronic Literature” is viewed as a *must have* given the constantly increasing volume of on-line information and the importance of being able to process this information properly. Seven of the topics under CDIO 3.2 “Communications” were also included (3.2.1 - 3.2.7) as essential subject matter that is closely aligned to this CEAB attribute. Some additional components of CDIO 3.2 make contributions that are not explicitly required by CEAB, covering things like negotiating, networking, and communication

in a foreign language. Although Canada is a bilingual nation, communication in more than one language is not explicitly required by the CEAB attributes.

“3.1.8 Professionalism: An understanding of the roles and responsibilities of the professional engineer in society, especially the primary role of protection of the public and the public interest.”

CDIO 2.5.1 "Ethics, Integrity, and Social Responsibility" is an essential aspect due to the social responsibility component. CDIO 4.1.1 "Roles and Responsibilities of Engineers" and CDIO 4.1.3 "Society's Regulation of Engineering" are also *must have* components for this attribute. Other items that could contribute include CDIO 2.5.2 "Professional Behavior" and the impact of engineering on society (CDIO 4.1.2, CDIO 4.1.4-4.1.7). These latter topics, although related to Professionalism, fit more appropriately under CEAB Attribute 3.1.9 and consequently they are only listed as a *could have*.

“3.1.9 Impact of engineering on society and the environment: An ability to analyse social and environmental aspects of engineering activities. Such abilities include an understanding of the interactions that engineering has with the economic, social, health, safety, legal, and cultural aspects of society; the uncertainties in the prediction of such interactions; and the concepts of sustainable design and development and environmental stewardship.”

The direct mapping to topics under CDIO 4.1 is expected, and all aspects of 4.1 are *must have* topics either here or under Professionalism. CDIO 4.3.1 “Understanding Needs and Setting Goals” is also essential as it brings in “ethical, social, environmental, legal and regulatory influences,” and the “probability of change” at the fourth level. Numerous other CDIO topics have the potential to contribute societal context, depending on how they are presented and system thinking will be invaluable in assessing the bigger picture, as it is throughout.

“3.1.10 Ethics and equity: An ability to apply professional ethics, accountability, and equity.”

The mapping to CDIO 2.5 is direct. CDIO 4.1 also provides contributions related to the societal context. Note the distinction made between ethics and regulation, which are often addressed together in a curriculum.

“3.1.11 Economics and project management: An ability to appropriately incorporate economics and business practices including project, risk and change management into the practice of engineering, and to understand their limitations.”

CDIO 4.2.7 must be combined with 2.1.4 to incorporate economics in a framework of uncertainty to manage risk. 4.3.4 explicitly addresses project management while many other topics have the potential to contribute experience of the limitations through a context of practice.

“3.1.12 Life-long learning: An ability to identify and to address their own educational needs in a changing world, sufficiently to maintain their competence and contribute to the advancement of knowledge.”

CDIO 2.4.5 addresses the self-awareness to identify needs, and integrate new general knowledge learned through 2.4.6 and current developments in engineering under 2.5.4, all *must have* topics.

APPLICATION

The global mapping in table 1 shows clear correlation between the CDIO and CEAB approaches that is not surprising. Its primary utility is in convincing administrators that we are on the right track in a single presentation slide. It is inadequate for detailed assessment, which requires at least the depth provided by table 2.

Even non-CDIO engineering programs can benefit from this analysis as a basis for validation of their curriculum through having a well thought out list of topic areas that can contribute to satisfying the CEAB attributes. Still, the largest benefit will be to CDIO programs whose curricula are already mapped to CDIO topics. They can validate their programs to the new CEAB requirements by demonstrating they have already addressed the relevant CDIO topics at an adequate level of complexity, as confirmed by their stakeholder surveys. Thus CDIO benchmarking and development documentation provides the direct support for accreditation through a rigorous forward mapping of CDIO topics to CEAB attributes.

Program audits are a part of CEAB accreditation and should also be part of ongoing program development under CDIO. The matrix of table 2 provides a back mapping of CEAB attributes to the topic areas where evidence for the existence of those attributes may be found, and through those topics back to course activities and deliverables that may be assessed directly.

CDIO Standards 2 and 12 require continuous curriculum development based on stakeholder input, and CEAB 3.1 requires “processes in place that demonstrate that program outcomes are being assessed in the context of these attributes, and that the results are applied to the further development of the program.” The mapping in table 2 allows stakeholder input based on either the 12 CEAB Attributes or the 19 CDIO Topics to be used to inform program development in both contexts.

CEAB Attributes are based on students at the point of graduation, thus assessment of these attributes will be concentrated towards the end of the program. We don't expect students to have all of these attributes earlier in their development. However, we can follow that development by linking the final attributes to syllabus topics that will be visited and revisited repeatedly throughout the program. That process can be tracked by an Introduce-Teach-Utilize curriculum analysis as part of the CDIO benchmarking process [2,5,6].

CONCLUSION

A program demonstrated to meet a reasonable collection of CDIO Syllabus Topics with outcomes at appropriate levels meets the CEAB Graduate Attributes requirements. The only exception is in the technical knowledge base where both standards lack detail that must be validated for each discipline or program separately.

A subset of the CDIO Syllabus has been identified as *must have* items for each CEAB attribute. That should not be interpreted to mean that addressing only those topics is sufficient to meet that attribute. There must also be sufficient integration to demonstrate the attributes within the larger context of engineering practice, represented in part by the multiple additional topics expected to provide contributions to each CEAB attribute.

This unidirectional mapping shows how a subset of topics from the third level of the CDIO Syllabus can adequately address the new CEAB requirements for Graduate Attributes, however it does not support the inverse mapping. A program that meets the CEAB Attributes does not necessarily meet CDIO standards. It must also be emphasized that this is not **the** subset of topics, but simply **a** subset that is adequate, and that some substitution could produce different flavours of CDIO programs that would also meet CEAB requirements. CDIO institutions are encouraged to adapt this mapping to meet accreditation needs specific to their programs using the spreadsheet provided electronically in the conference proceedings or available from the authors.

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THE TRANSITION INTO UNIVERSITY: WHAT ENGINEERING STUDENTS KNOW

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COGENT

ABSTRACT

This work arose from the perception that it would be extremely useful in delivering and improving first-year undergraduate engineering modules if the staff could be given a profile of the knowledge and understanding of the incoming student cohort. This knowledge and understanding is usually not well captured or described by prior qualifications, because it would ideally embrace both technical understanding and also practical skills and a general understanding of the societal context in which engineering is being taught. We therefore developed a set of web-based diagnostic and support tools designed to identify more clearly the attributes of students entering engineering programmes in the UK in 2010 and to support their transition into university.

The project team devised 50 questions for incoming students, developed a web-based tool for their delivery during the first two weeks of the academic year and an initial data query tool for retrieval of the resultant data. This questionnaire has been run with more than 300 students in four universities and some initial conclusions have been drawn. There are differences in detail but these four first year student cohorts are quite similar in their incoming knowledge and skills.

KEYWORDS

Transition; prior knowledge; induction into engineering; first year experience;

BACKGROUND

The project arose from the perception that it would be extremely useful in delivering and improving first-year undergraduate engineering modules if the lecturing staff could be given a clear profile of the knowledge and understanding of the incoming student cohort. This knowledge and understanding is not well captured or described by prior qualifications (such as

A-levels in the UK), because it would ideally embrace both technical understanding and also practical skills and a general understanding of the societal context in which engineering is being taught.

The aim of this project was to scope and test both content and mode of use of a set of web-based diagnostic and support tools designed to identify more clearly the attributes of students entering engineering programmes in 2010 (and beyond) and to support their transition into university.

IMPLEMENTATION

The implementation of the project involved four inter-connected and mutually dependent aspects: These were the development of the questionnaire, the development of the on-line test delivery environment, the delivery of the tests to the selected student cohorts and the subsequent analysis of the large amount of data thus collected. These four aspects will be considered in turn:

The questionnaire:

The content of the questionnaire covers, albeit with only a few questions each;

- The technical knowledge which an incoming student should have gained from prior study (principally physics, chemistry and mathematics);
- Practical skills (such as use of workshop hand tools);
- Familiarity with major examples of engineering in society (such as nuclear energy), and;
- Knowledge of adjacent areas of developing importance (such as biology).

A target questionnaire completion time of less than one hour dictated that the number of questions should be limited to 50 or 60 and the content therefore represents a compromise between the breadth implied by the above list and the depth desired by the future teachers of these students. The topics to be covered were eventually agreed to be:

- Chemistry
- Energy – kinetic and potential
- The Workshop
- Nuclear Power
- How they work – mechanical parts
- General knowledge – environmental, evolution and biology
- Electronics and optics
- Office IT
- General physics – forces and motion
- General engineering – loads and gravity
- Materials properties
- Maths – trigonometry, binary and equations

About 70 questions were written by members of the team, of which 50 were deployed in the first questionnaire. Considerable time was spent refining the wording of the selected questions: to use a vocabulary and style appropriate to the intended cohort; to devise unambiguous multiple choice questions that each addressed a single concept or idea; to design answer choices that would unearth common misconceptions; and to ensure questions were culturally and linguistically neutral. This was probably the most difficult task of the project.

A “not sure” option was included in as many questions as possible, and it was emphasized to the students that they were not being “marked”. Three specimen questions are reproduced as Appendix 2, and the complete set can be obtained from the author on request.

The delivery environment:

No piece of commercial software was found to offer the required flexibility in delivery (any student, anywhere) and data collection and analysis (free access by all partners to all results in a spreadsheet). A web-based questionnaire delivery system and data retrieval system was therefore developed, which offers almost any type of question (including graphics if necessary) and enables the output of every answer in raw spreadsheet form for analysis. The data input by the student, prior to answering the questions, comprises:

- Host institution [from a drop-down list of partners]
- Programme of study [from a drop-down menu of programmes provided by each partner]
- Highest prior qualification [A-levels, apprenticeship, Baccalaureat, Foundation Year, NVQ, SQA Advanced Highers, SQA Highers, Other]
- Nationality (effectively fee status) [UK, EU, Other]
- Email address [for response and feedback – need not be university address; not a requirement if feedback is only to be given immediately]

Clearly these are tailored to the UK environment, but could easily be modified to reflect local conditions in other countries. The rubric at the beginning of the questionnaire (reproduced as Appendix 1 below) emphasises the rationale behind the exercise and is intended to remove apprehension about the test from the students’ minds.

The questionnaire can be seen and used at www.stem-transition.ac.uk. Three specimen questions are in Appendix 2.

Delivery to the students:

Each partner university chose how to deliver the questionnaire. All elected to do it in week 2 of the first semester, when almost all students would have completed their registration and have email and web access within the university. Most delivery was in the context of a first-year study skills or core skills module. Response rates were better when the exercise was carried out in a timetabled class session (eg 112 completed questionnaires from a possible 154 students at University A) and lower when the students were told about the exercise and asked to do it later (e.g 93 completed questionnaires from a possible 270 at University B). One complete programme cohort at University C missed the opportunity because of a local system crash, but the response rate from the other University C cohort was good.

It did not prove possible to implement the automatic email to each student who completed the questionnaire, and thus the students received no feedback on their performance this year. The feedback should identify gaps in knowledge, understanding and experience and should point students towards learning resources to help them improve. It is an urgent priority to ensure that this is implemented next year.

For the same reason, and additionally because it is difficult to locate support resources at exactly the appropriate level for each question, support was not offered individually to students.

However there are a number of semi-generic sites which offer explanations for almost every question. These include:

www.mathcentre.ac.uk
www.howstuffworks.com
www.raeng.org.uk/education/diploma/maths/default.htm
<http://sls.uwe.ac.uk/ls/orgchem/>

The authors are currently implementing a system of feedback to every student who completes future questionnaires.

Data analysis:

All the data, from a total of 312 students, is available in spreadsheets. Partners from the individual universities have downloaded their own cohort data and are using it in different ways. Centrally we have so far analysed the data at the following levels:

1. Correct answers to each question at university level (i.e. one set per university) and in aggregate (sum of all four universities);
2. Not-sure answers to each question at university and aggregate levels;
3. Correct answers per question-group at university and aggregate levels;
4. Prior qualification, and;
5. Nationality;

We have not yet had the time resource to analyse the data in terms of:

6. Programme of study (i.e. Engineering discipline). The number of returns for each discipline are also too small to give significant information at this stage.

DISCUSSION AND CONCLUSIONS

Barriers

The key barriers to success and on-time delivery were found to be:

- The difficulty of writing good questions – tuning the questions took a great deal of meeting time;
- Restriction of the questionnaire length in order to enable students to complete it within one hour. In practice we over-estimated the time required and could add several more questions next time. However the restriction of time still means that each topic can only be explored through a small number of questions – essentially a sampling approach to the students' knowledge, rather than a comprehensive survey;
- The reliable delivery to a large fraction of the student cohort. This is particularly difficult for those cohorts without a single class scheduled for a computer laboratory;
- The difficulty of delivering tailored support to every student, for every question. With the benefit of hindsight this was never likely to be achievable within this project: Pearson have spent millions of dollars developing good feedback for assessment questions (e.g. in Mastering Engineering) and still only cover a fraction of the ground we are surveying.
- Some students gave fake email addresses, indicating that (despite our efforts to persuade them otherwise) they were concerned about the results being used against them. The behaviour of a significant minority of students who – despite all our advice to the contrary – treated the questionnaire as an assessment of them, merits further exploration (see below under Recommendations for others).

Conclusions and evidence of success

The key indicator of success is that all partners are enthusiastic about deploying the questionnaire in future years (after some necessary fine tuning of the questions).

Although it is the key task of each partner to interpret and use the data from their own students to improve engineering education within their own institution, there are some overall conclusions which can be drawn at this stage. These include:

1. There is a wide range of highs and lows in understanding across all topics;
2. There is a large degree of similarity between the student cohorts from the four universities, with only the University C students demonstrating a significantly different pattern of knowledge in some areas.
3. Only five of the 50 questions were answered correctly by more than 90% of all students. After debate it was agreed that there is value in retaining these questions for two reasons: they help give the students confidence, and they should be useful as a check that key topics remain well understood over the next few years (or not, if that is the finding!);
4. Many students have clearly learned something about topics which are not directly taught to them. However there is generally a lower understanding, across all cohorts, of topics which might be regarded as scientific or engineering “general knowledge” (e.g. evolution, nuclear power, photosynthesis);
5. On average only 6% of responses were “not sure”, and these were largely clustered around 8 questions with not-sure responses of 15–40%. This should help us identify key misconceptions. There was a weak correlation between the average mark for a question and the number of not-sures – in other words there was a slight tendency for poorly-answered questions to attract a larger number of not-sures
6. Only 8 questions were answered correctly by less than a third of the students. The topics of these questions ranged across almost all topic areas, including chemistry, physics (mechanics), materials, general knowledge and mathematics. These are the most important general lacunae which should be brought to the attention of staff teaching first-year students.
7. In terms of initial qualifications, students with A-levels or a Baccalaureate (i.e those with slightly more academic qualifications) performed about six percentage points (59% vs 53%) above those with other qualifications, including those who undertook a foundation year before entering their first year. They were also slightly less inclined to answer “not sure” (6% vs 8%)
8. In terms of national background, UK students (actually those with a residential qualification sufficient for them to pay “home” fees) performed slightly better than those from the EU and ten percentage points (59% vs 49%) better than those from other countries (“Overseas”, likely to contain many students from China, India and Malaysia).

The full data spreadsheets from which the above interim conclusions are drawn are available from the author at goodhew@liv.ac.uk.

Some of the conclusions we can draw appear to be generic, at least in the UK. For example all cohorts tested show considerable weaknesses in their understanding of chemistry, nuclear power, electronics, optics and the properties of materials. They are particularly ignorant about environmental and biological issues (average score 10%). They all did well on the questions about energy, workshop tools and MS Office. However since each of these areas is only tested with a few (three to six) questions we can have little confidence in the reliability of these subject-

specific conclusions. This situation will be improved greatly if we succeed in running the questionnaire with more students and more institutions in 2011 and 2012. It should be possible to collect >600 student responses in 2011 and >1000 in 2012, greatly increasing the statistical significance of our conclusions and making it worthwhile to examine the data at the discipline level (mechanical, electrical, etc). Of course if other institutions (especially CDIO partners) choose to join the experiment then our statistical base will improve rapidly, and we could consider drawing international comparisons.

Recommendations for others

Anyone contemplating deploying this questionnaire or developing a similar tool would be well advised to read the whole of this report and to speak to one or more of its authors.

A key issue is how the questionnaire is delivered to students. As was explained above, it proved difficult to persuade students that this is not a test of their status or progress but a snapshot of the cohort to help staff to match their teaching to the whole student cohort. Our recommendations are that this effect is likely to be minimised when the exercise is carried out with a “captive” class (e.g. all together in a computer lab) immediately following a clear explanation of the purpose of the questionnaire. It would be an interesting research project to explore student attitudes and the effectiveness of various differently-nuanced explanations – some of which could perhaps emphasize more strongly the altruistic nature of the whole exercise.

Concluding remarks

This has been a highly successful project within the confines of very limited funding. The whole team (4 institutions plus Cogent) together with a likely three additional universities (CDIO partners Lancaster, Aston and Strathclyde) are very keen to improve the questionnaire and use it in September/ October 2011. This work is ongoing. Other institutions wishing to deliver the questionnaire to their own students should contact the corresponding author. Their programmes can be added with minimal effort.

Appendix 1

Rubric presented at the top of the questionnaire:

“The questionnaire we are asking you to undertake is for the benefit of yourself and future generations of students. We are trying to establish what you and your fellow-students as a whole know and understand about engineering and some of the science and maths which underpins it. If we can find this out, we can modify the modules you will be attending in order to fill in gaps, and exploit strengths, which your particular group of students have.

This is NOT a test, it carries no marks and your results will not be used by anyone to assess you. Staff at your university will not have access to individual results, only to the combined results of your whole year group. However to help you understand your current state of knowledge and experience you will receive, after completing the questionnaire, an analysis of where you have gaps in your knowledge, together with some suggestions as to how you might like to fill these gaps. This is simply to help you be better prepared for your engineering studies.

Please answer the questions as honestly and quickly as you can. We do not want you to spend too long doing this, and if you seek help or look up the answers then your results will be of no use to us in improving your modules, and also very little use to you! If you are curious to know more about any topic, then look it up after you have finished the questionnaire.

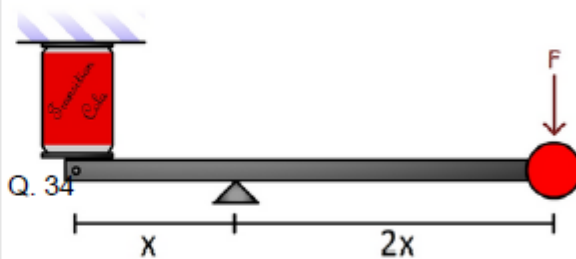
Thank you for your cooperation.”

Appendix 2

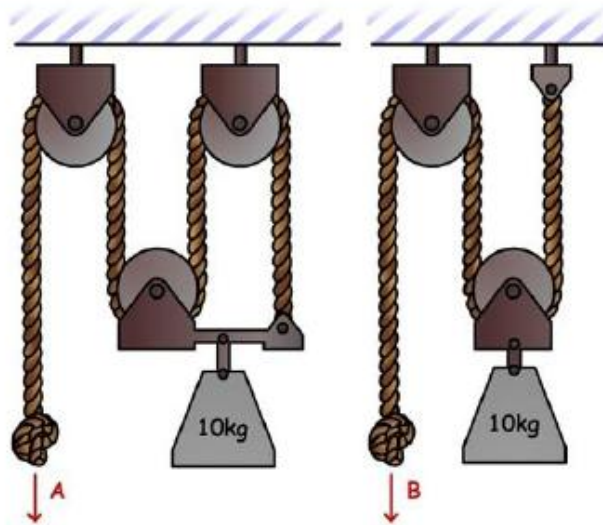
Three specimen questions (with answers checked):

A diagram of a simple can crusher is shown on the right. The downwards force labeled "F" is:

- half of that exerted on the can
- equal to that exerted on the can
- double that exerted on the can
- one third of that exerted on the can
- I'm not sure



How They Work – Mechanical Parts

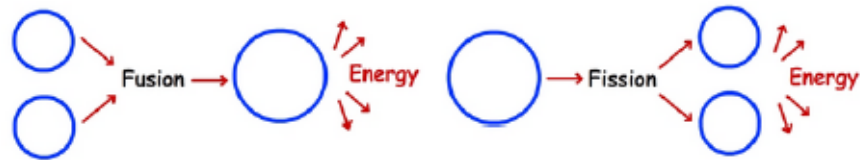


Above are two similar pulley systems.

Pulling rope A would be:

- easier than rope B and would lift the weight further
- more difficult than rope B and would not lift the weight as far
- I'm not sure
- easier than rope B but would not lift the weight as far
- more difficult than rope B but would lift the weight further

Nuclear power



1

Nuclear power stations in the UK are:

- mostly built around fusion reactors
- all built around fusion reactors
- mostly built around fission reactors
- all built around fission reactors
- half built around fusion and half built around fission reactors
- I'm not sure

Neutrons are emitted:

- in a fusion reactor but not in a fission reactor
- in both fission and fusion reactors
- in a fission reactor but not in a fusion reactor
- I'm not sure

BIOGRAPHICAL INFORMATION

Peter Goodhew is Emeritus Professor in the School of Engineering, University of Liverpool, UK. He is one of the Directors of CDIO and the joint Leader of the UK & Ireland region. He is interested in many aspects of engineering education and has recently published a short book on the subject: "Teaching Engineering", downloadable from <http://www.materials.ac.uk/resources/Teaching-Engineering.pdf>

Dr Matt Murphy, Dr Charles McCartan, Dr James Ren, Professor Peter Myler and Dr Caroline Sudworth are partners in the STEM Transition project.

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ENGINEERING REASONING AND VISUALIZATION AS ANALYSIS TOOLS FOR BOP DESIGN

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ABSTRACT

Base of the Pyramid (BOP) Design is a human-centred process that requires an in-depth look at causes and effects of poverty. Engineering reasoning (R. Niewoehner) and visualization tools were used to give 740 first year engineering students an opportunity to understand the complex issues in communities in developing countries (Fig. 1). Based on their analysis, students developed design solutions for one of seven interconnected areas: Water, Health, Energy, Agriculture, Shelter, Transportation, and Education. This project had students working in groups of four over a period of seven weeks.

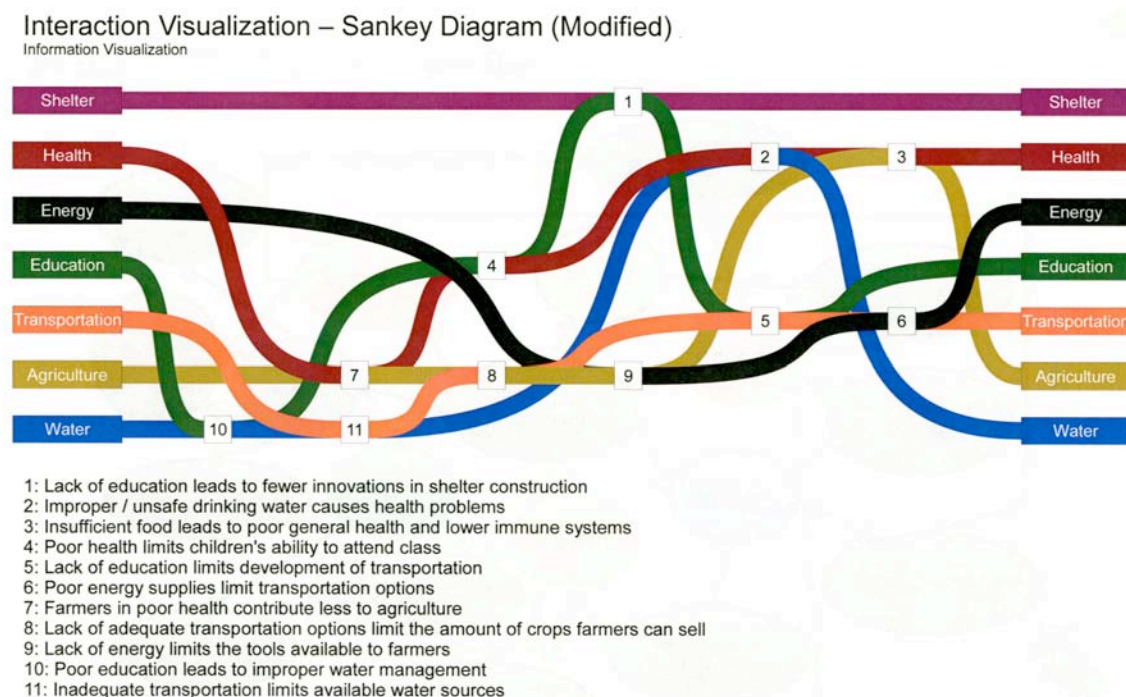


Figure 1. Understanding complex issues – student visualization

The paper will discuss the project as a whole, student observations, analysis, and their subsequent increased empathetic view towards complex issues in this area of 'design for the other 90%'. Empathy requires two components: "the first is that there are no 'dumb users', only dumb products, and the second is the appreciation of context and avoiding for example

assumptions about the availability of spare parts and trained maintenance, or very specific assumptions about a user's familiarity." [1] Examples of design prototypes, including accompanying brochures, will also be discussed.

KEYWORDS

Engineering reasoning, information visualization, Base of the Pyramid design

INTRODUCTION

In the Fall of 2009, our first year Design and Communications course ended with a 7-week Engineers Without Borders (EWB) project developing design solutions for communities throughout Africa. This project can be described as a Conceive Design project if we look at the CDIO (Conceive, Design, Implement, Operate) syllabus, specifically at section 4. CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT:

4.1. EXTERNAL AND SOCIETAL CONTEXT

- 4.1.1. Roles and Responsibility of Engineers
- 4.1.2. The Impact of Engineering on Society
- 4.1.5. Contemporary Issues and Values
- 4.1.6. Developing a Global Perspective

4.2. ENTERPRISE AND BUSINESS CONTEXT

- 4.2.1. Appreciating Different Enterprise Cultures
- 4.2.2. Enterprise Strategy, Goals and Planning

4.3. CONCEIVING AND ENGINEERING SYSTEMS

- 4.3.1. Setting System Goals and Requirements
- 4.3.2. Defining Function, Concept and Architecture

4.4. DESIGNING

- 4.4.1. The Design Process
- 4.4.2. The Design Process Phasing and Approaches
- 4.4.3. Utilization of Knowledge in Design
- 4.4.4. Disciplinary Design
- 4.4.5. Multidisciplinary Design
- 4.4.6. Multi-objective Design

This EWB/BOP design project had 740 first year engineering students working in groups of 4 over a period of 7 weeks. Students started their introduction to the project with two workshops. The root causes of poverty workshop had students create mind maps of all related causes and effects concerning an African community. The second workshop, Water for the World, had students build and test water filters based on an assigned country profile. The profile determined GDP, available funds, literacy rates, and varying product costs. Students were subsequently given one of a variety of different community profiles and were asked to analyze the document using 'Engineering Reasoning', a critical thinking guide designed to help students assess document accuracy and neutrality. Visualizations of 7 research areas connected to the community were required so students could see the 'big' picture. Students then continued with one of these areas to develop a design solution. This

design solution could take the form of a new product, a redesign of an existing product, or a system design. An open house was held where students made design presentations via prototypes, posters and brochures.

Section one of this paper will describe briefly the motivation and overview for this project. Section two of this paper will discuss tools and workshops that students encountered leading up to this project and the application of these tools to the design for base of the pyramid (BOP – see also Appendix 1) communities. Section three will look at student analysis of case studies using Engineering Reasoning and the periodic table of visualization methods seen in Figure 2. Finally section 4 will trace a selection of results of the analyses to final design outcomes.

A PERIODIC TABLE OF VISUALIZATION METHODS

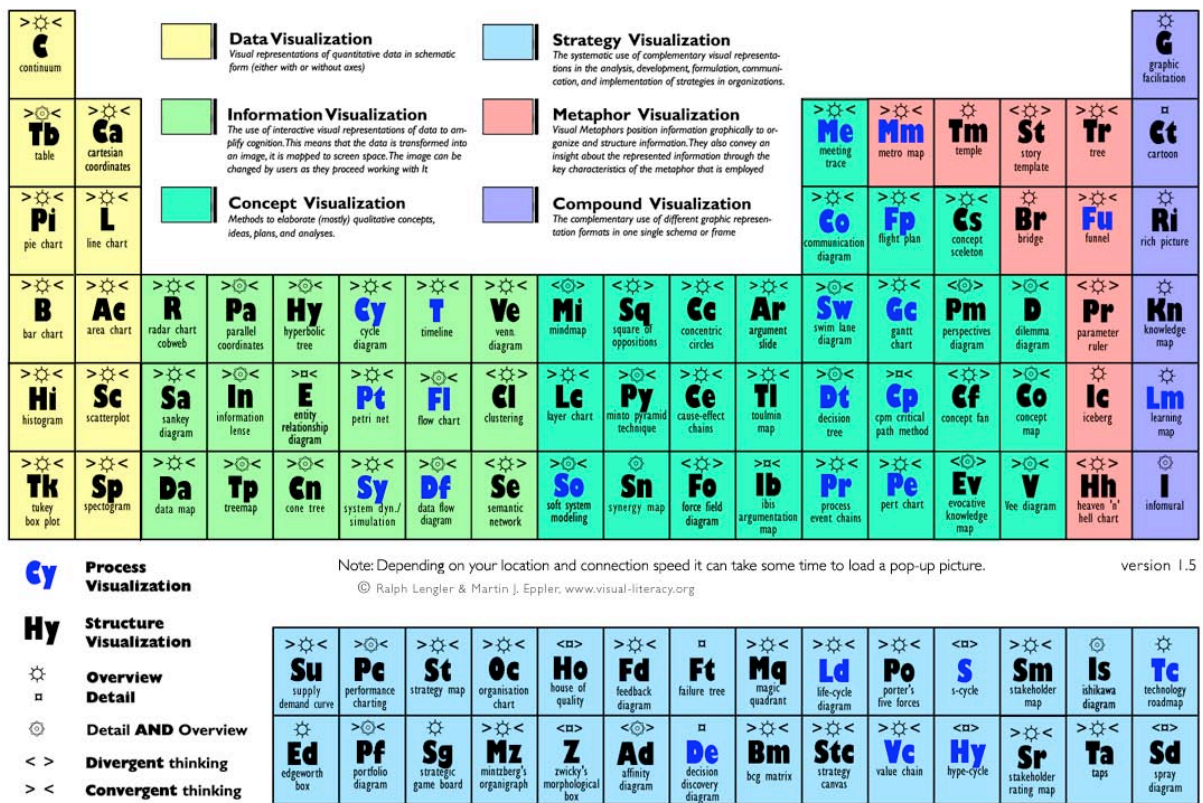


Figure 2. Periodic Table of Visualization Methods [2]

1. EWB MOTIVATION AND OVERVIEW

The main goal for this project was to encourage critical thinking among first year students with regards to global engineering and to have students become more socially conscious of the impact of their actions on society, locally and globally.

EWB wanted to achieve the following objectives:

- Encourage students to examine their ideas of the role of engineers in society, as well as their definition of the engineering discipline.
- Have students explore the concepts of development and social change using EWB as a reference point
- Encourage students to discuss the importance of a multidisciplinary outlook on engineering projects and development.

- Support students to take on a more cooperative approach in the design process as opposed to a competitive approach.
- Provide students with opportunities for reflective learning and group discussion.
- Enhance student understanding on systems theory in terms of complexity and interconnectivity.
- Encourage students to examine what defines the success of a development project.

The project deliverables and components were as follows:

1. Students, after being sorted into new groups, completed EWB's root causes of poverty and the water filter workshop.
2. Each group submitted a team contract, laying out timelines, goals, roles and penalties for failure to meet commitments, in order to limit group problems and to ensure a smooth project flow.
3. In teams, students completed a document analysis of their community profile using Engineering Reasoning, and using that analysis, determined the types of problems that people of that community face.
4. Teams examined seven interconnected areas (Water, Health, Energy, Agriculture, Shelter, Transportation, and Education). Visualizations of the complex issues of the community, using the Visual Periodic Table, were developed to aid the students in understanding the complexity of community development.
5. Students were encouraged to take new outlooks on the types of possible solutions for their community, keeping in mind the complexities and interconnectedness of the topics assigned. Each team conducted research on their community, the country the community is located in, and the feasibility of one of their possible solutions (covering one of the 7 research areas). This information was presented to the lab in an oral presentation format.
6. Using the presentation as a starting place, each team developed, depending on their solution, EITHER: a working prototype of their solution, or an essential functional element of that solution; a representational prototype (model) of their solution (where appropriate); or a website detailing their solution. All designs in addition had to be sustainable and environmentally sound. Each team also developed a poster detailing background, essential information and usage possibilities for their solution.
7. All solutions were presented during Lab Open Houses at the end of the semester.

2. WORKSHOPS AND TOOLS

The EWB workshops served a dual purpose for this project, one directly related to the content of the project and one related to course goals. For the course-related goals, these workshops were a first introduction to the types of seminars and workshops that most engineers participate in to upgrade their skills and to expand their technical portfolios. Engineering is a profession that encourages life-long learning, and as new issues and technologies arise, workshops to understand challenges are not only wise, but necessary.

2.1. Root-causes of poverty workshop

The objective of the root-causes (Fig. 3) of poverty workshop was to gain an understanding of the complexity of interrelated factors that influence the lives of people in the developing world.

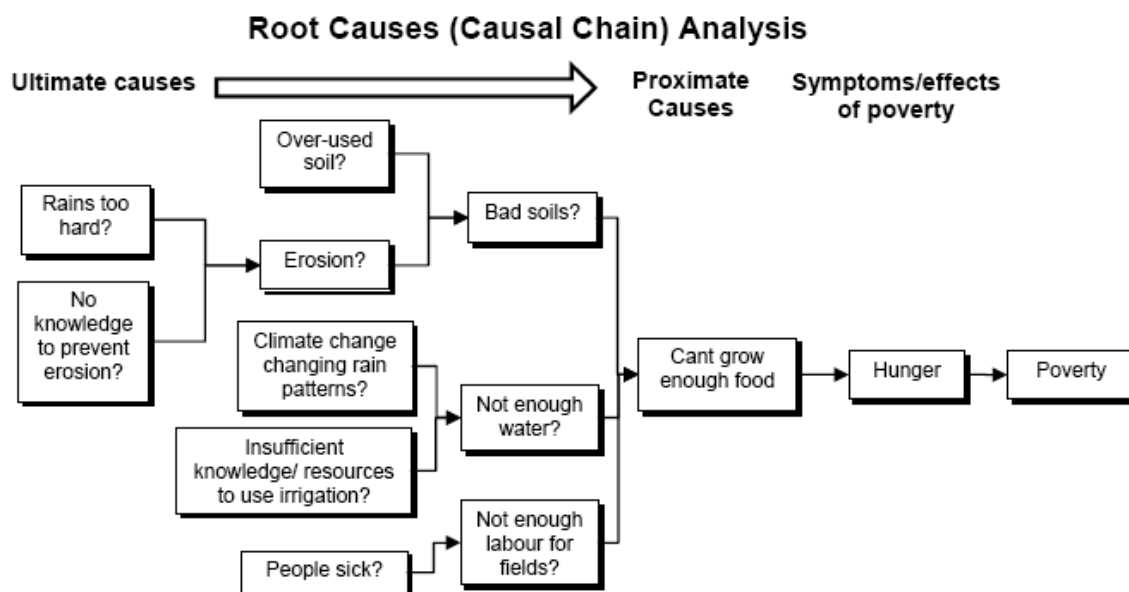


Figure 3. Root Causes Analysis

Seventy percent of the world's poor live in rural areas, thus it is important to understand their situation. This *root-causes of poverty* workshop described the challenges of a farmer by the name of Ziem in the Sahel region of Africa:

Rural farming households depend first and foremost on the ability to grow crops to earn their livelihood. These crops are either consumed by the households or sold to market. The intermittent rains lead to a short growing season. Increased land intensity (more people from the high birth-rate) has reduced available cropland, which means that fields are used more frequently. This leads to decreased nutrients in the soil, and therefore reduced yields. Fluctuating rain patterns also lead to decreased – or more uncertain – yields. The need for labour in the fields means that children cannot attend school. Increased cultivation and heavy rains has led to erosion.

A lack of crops tends to lead to a lack of food, which might be a proximate cause of poverty, with the above complications linked to more ultimate causes. A lack of food is also an effect of poverty, because people lack the resources to overcome those challenges in the chain.

People also need access to water for drinking. In this region the water table is low (deeper than hand-dug wells can reach), so people depend on surface water, which is typically not clean water. Boreholes, which tap into clean water, can help but are expensive. In this case they are also far from other communities, meaning people spent too much time getting water. In this case, the lack of access to clean water isn't because they don't know how to get it – it is because they don't have the resources to pay for the borehole (associated with this is that the borehole drilling process may be too expensive for technical or monopoly reasons.)

There is no sanitation in the communities, likely because it is not known that this is important. (The West only developed the germ theory of disease in the mid 1800s – before that we had the same disregard for sanitation.)

No electricity means no light for working/studying at night, and no energy to power food-transformation equipment, causing women to spend a lot of their time at manual labour. There is no indication why there is no electricity, but lack of resources and/or lack of governance (which typically supplies electricity) could be a problem.

Isolation – being far from a road, means that it is more expensive to buy goods (or to bring them to the community); and to sell farm produce; and it means that district health workers and teachers are unlikely to want to go to the community. The lack of a road is not explained but could be the result of poor governance – the municipal/regional government might not listen to the people. Likewise a lack of resources to build a road is usually a problem.

Cultural factors play a role. High numbers of children reduce land availability. And high child mortality rates leads to having lots of children because you don't know how many will survive.

Similarly, a lack of focus on education (Ziem's father) reduces other opportunities – for example, getting a job.

There is also a culture of dependence on outside factors (another NGO, God) for solutions.

Other people's vulnerability affects people, who have to take on their burdens (e.g. a brother taking his sibling's wives if his sibling dies).

Education is a way out, and a way to improve one's life even if one stays, but we have seen a number of reasons why it is hobbled: kids working in the field or teachers who don't want to live in a remote community.

It is important to highlight the precariousness of their existence. After a bad harvest and thieves stealing some cows, Ziem was unable to recover.

Lack of sustainability of "interventions/projects" can be seen in the example of the broken well. This shows that local people need to be able to repair on their own – or access repair technicians – if improvements are to be sustainable.

Poor governance. Was also touched upon: authorities not repairing the roads or ensuring that the teachers are in the school. This is typically a widespread problem (e.g. more of an ultimate cause) of poverty. In Africa it can be explained by the arbitrary country delineations during colonization (with subsequent tribal animosities), and by a natural tendency for national governments to implement pro-urban, anti-rural policies (such as food marketing boards which artificially depress food prices, benefiting urban consumers and harming rural farmers) because governments are typically overthrown by urban unrest. [3]

Students were asked to create a *root-causes of poverty* map similar to Figure 2 to show the complexities surrounding a story such as Ziem's. The case studies presented to them for their final project were similar but longer (which is why this one was presented as an example).

2.2. Water for the World workshop

The second workshop was a hands-on water filter workshop entitled *Water for the World*. Students were given a lecture on the importance of global water issues. The lecture included a water quiz to make students realize local and global water shortages and how closely these are connected. After the introduction the EWB volunteer group set up a simulated 'water filter' store: this store sold various water filter ingredients for a range of prices. Students worked in 7 groups of 4 in 4 connected lab spaces for a total of 28 groups. Each group had been given a country profile. Countries ranged from Malawi to the United States. Basic statistics of each country were provided and a wallet. These wallets contained pro-rated amounts based on the GDP of each country: Malawi had \$20, amounts increased from there up to the US, which had \$1,000. Teams were asked to design a water filter based on their resources. In some labs teams quietly worked on their filter designs, which were signed off by EWB volunteers before students were allowed to purchase materials (Fig. 4). In other labs teams were selling design sketches to the US or Canada (Fig. 5) or offering to purchase materials from the 'store' – some materials for developing countries were more expensive than for countries from the developing world (Fig. 6).

At the end of the workshop a filter test was done with all teams. Often the 'developing' countries created better filters because they had given a lot of thought to the right materials before purchasing. The richer countries often designed along the lines of 'bigger is better' or 'more material, clearer water'. In these cases no thought had been given to the properties of materials.

Design Process

1. Defining the Problem
 - Requirements, Current Solutions, Constraints
2. Formulating Solutions
 - Concept Generation and Selection
3. Developing Models and Prototypes
4. Presenting and Implementing the Design
 - Before you “purchase” anything, complete steps 1 and 2. You can go and take a look at what you can purchase if you want.

Figure 4. From EWB Water for the World workshop slides: Design before you build

How does the activity relate to the real world?

Activity	Real World
Different amounts of money per group	Based on actual country's Gross Domestic Product (GDP)
Illegible instructions	Based on actual country's illiteracy rate Lack of education and access to information
Resourcefulness of groups with little money	People in poorer countries have their own coping mechanisms
Collaboration between countries	Richer countries formed the G8 and OECD Poorer countries formed the Group of 24
Patronizing attitudes, charity	Goes with power, as long as it does not compromise own people's demands

Figure 5. From EWB Water for the World workshop slides: Real world comparisons

Materials Available						
Material	Unit	United States	Canada	Cameroon	Ghana	Ethiopia
Filter cloth	Square	\$5	\$10	\$1	\$1	\$1
Cotton Ball	Each	\$5	\$10	\$1	\$1	\$1
Gravel	Cup	\$10	\$10	\$10	\$10	\$10
Sand	Cup	\$20	\$20	\$10	\$10	\$10
Activated Charcoal	Cup	\$50	\$50	\$30	\$30	\$30
Rubber Band	Each	\$5	\$5	\$1	\$1	\$1
Water	Cup	\$10	\$5	\$10	\$10	\$20

Figure 6. From EWB Water for the World workshop slides: Cost variation

3. STUDENT ANALYSES OF CASE STUDIES

3.1. Engineering Reasoning

Students were given one of a number of different community profiles (comparable to Ziem's – see section 2) and were asked to analyze the document using 'Engineering Reasoning', a critical thinking guide designed to help students retrieve the most important information from the case study. This publication by the Foundation for Critical Thinking gives students tools to analyse a document quickly by providing the right questions to ask when reading a text critically. It looks at universal structures of thought. This was the second time in the semester students encountered this critical thinking model. At the start of the semester in one of the first workshops of the year, students were using the Engineering Reasoning booklet to analyse an executive summary of a Columbia Accident Investigation Board (CAIB) report from 2003. The author had experienced the same format in a humid 35-degree classroom in Singapore in the summer of 2009 and in a moment of delirium decided to try this with 740 17-year olds. Running this same workshop not only taught the students how to format an executive summary and what to include, but also brought the topic of document analysis out of a purely communications realm and into the, in their minds more important, engineering realm. It was after all about NASA. Using Engineering Reasoning a second time in a global societal responsibility project gave the project an air of legitimacy, which had not happened before in assignments of a similar nature. Figure 7 shows a concise checklist for students for engineering reasoning [4].

A Checklist for Engineering Reasoning

1. **All engineering reasoning expresses a *purpose*. Take time to state your purpose clearly.**
 - Distinguish your purpose from related purposes.
 - Check periodically to be sure you are still on target.
 - Choose realistic and achievable purposes.
2. **All engineering reasoning seeks to figure something out, to settle some *question*, solve some *engineering problem*.**
 - Take time to state the question at issue clearly and precisely.
 - Express the question in several ways to clarify its meaning and scope.
 - Break the question into sub-questions.
 - Determine if the question has one right answer, or requires reasoning from more than one hypothesis or point of view.
3. **All engineering reasoning requires *assumptions*.**
 - Clearly identify your assumptions and determine whether they are justifiable.
 - Consider how your assumptions are shaping your point of view.
 - Consider the impact of alternative or unexpressed assumptions.
 - Consider the impact of removing assumptions.
4. **All engineering reasoning is done from some perspective or *point of view*.**
 - Identify your specific point of view.
 - Consider the point of view of other stakeholders.
 - Strive to be fair-minded in evaluating all relevant points of view.
5. **All engineering reasoning is based on *data, information, and evidence*.**
 - Validate your data sources.
 - Restrict your claims to those supported by the data.
 - Search for data that opposes your position as well as alternative theories.
 - Make sure that all data used is clear, accurate, and relevant to the question at issue.
 - Make sure you have gathered sufficient data.
6. **All engineering reasoning is expressed through, and shaped by, *concepts and theories*.**
 - Identify key concepts and explain them clearly.
 - Consider alternative concepts or alternative definitions of concepts.
 - Make sure you are using concepts and theories with care and precision.
7. **All engineering reasoning entails *inferences* or *interpretations* by which we draw *conclusions* and give meaning to engineering work.**
 - Infer only what the data supports.
 - Check inferences for their internal and external consistency.
 - Identify assumptions that led you to your conclusions.
8. **All engineering reasoning leads somewhere or has *implications and consequences*.**
 - Trace the implications and consequences that follow from your data and reasoning.
 - Search for negative as well as positive implications (technical, social, environmental, financial, ethical).
 - Consider all possible implications.

Figure 7. Engineering Reasoning Checklist

In previous years students were reluctant to take 'social' case studies seriously, complaining that this was not *real* engineering. By tying the Engineering Reasoning document to this analysis exercise students started to invest in the project straight away. Appendix 2 shows a set of student responses to the Engineering Reasoning checklist based on one of the case studies provided by EWB. The fact that this group started with the main purpose of this '*engineering*' article was encouraging:

MAIN PURPOSE

The main purpose of this engineering article is to introduce a small village named Changnayili in Ghana. The author focuses on five areas to describe the living conditions of the Dagoomba people, one of the major groups in the Northern Region. The author portrays the Dagoomba people living in poverty by describing their culture, geography, socio-economic conditions (including education), living conditions and energy sources. In each part, the author also lists some challenging problems that these people face.

3.2. Community profile visualization – Seven areas of Research

The class of fall 2009 consisted of 740 students divided into 24 lab sections of 25 to 30 students each. Four sections are run at a time for a total of 6 lab sessions of 4.5 hours each. Each section was given a variety of case studies to minimize copying and design 'osmosis'. Students were asked to start researching 7 interconnected areas within their case study. These areas were as follows:

- Water,
- Health,
- Energy,
- Agriculture,
- Shelter,
- Transportation,
- Education

The majority of connections had already been discovered during the Engineering Reasoning assignment. In a way this exercise was visualizing the Engineering Reasoning checklist for their assignment community.

They were asked to create maps and other data visualizations charting the connections and dependencies between the seven areas of focus. They were given the Periodic Table of Visualization as a starting point and each team of 3 or 4 was asked to create different visualizations using the *same* information. This exercise was intended to teach them about data visualization and about how to show the same information in a variety of ways (Figs. 8 – 10) show the visualizations of one group of students). It was also intended to show the students how a change in one area might influence a shift in another.

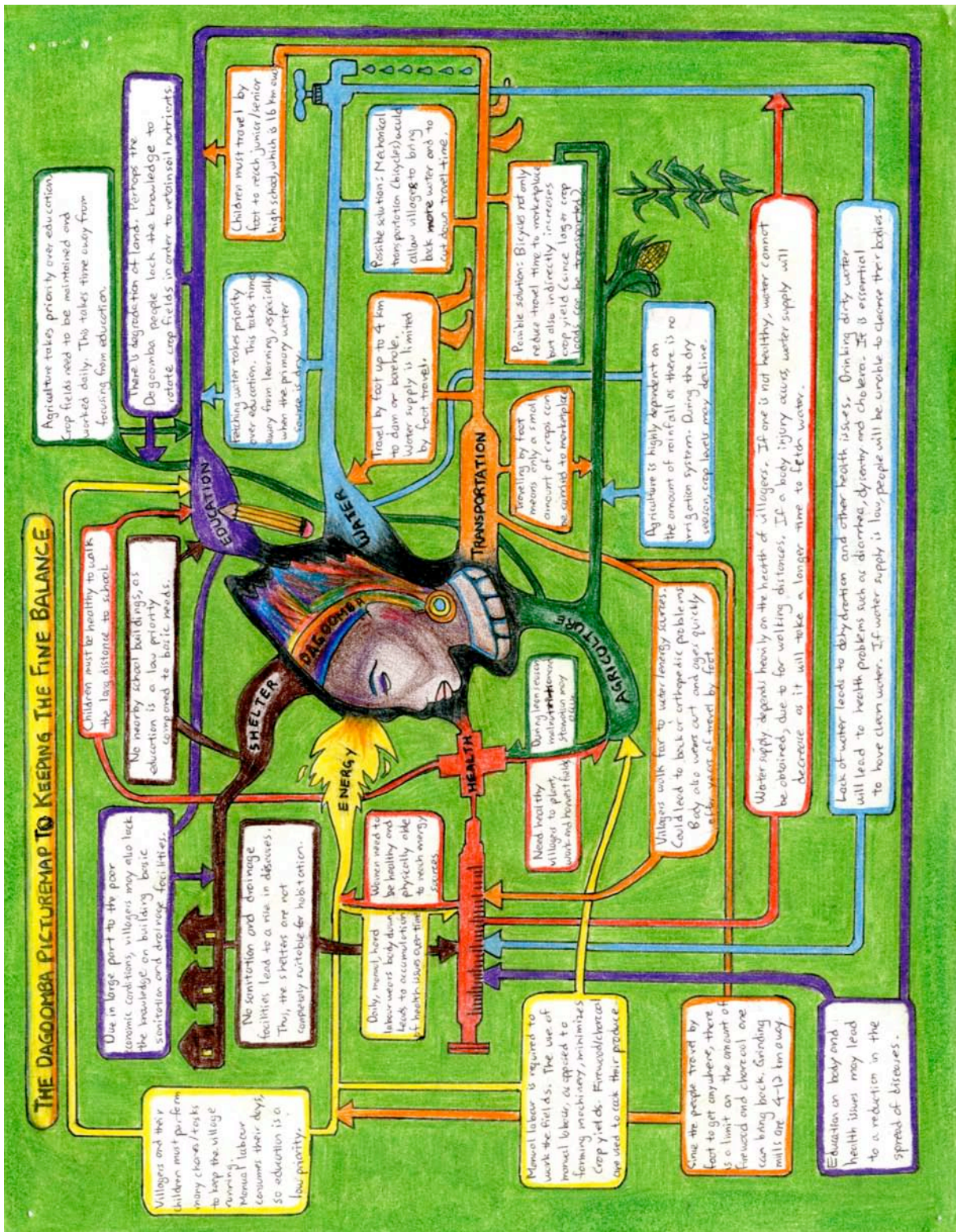


Figure 8. Group GA3 Visualization 1



Figure 9. Group GA3 Visualization 2

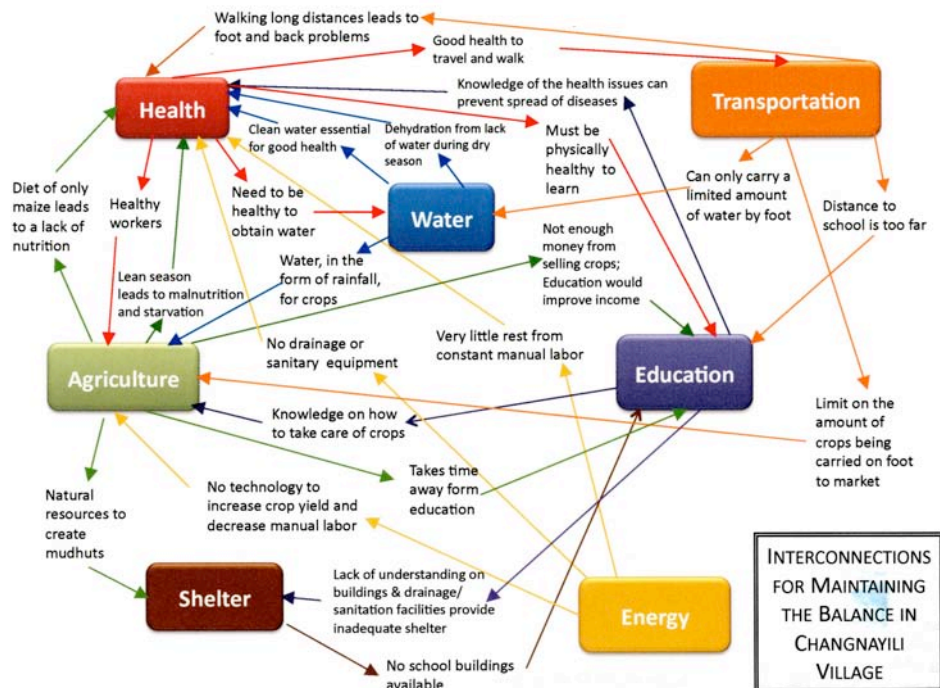


Figure 10. Group GA3 Visualization 3

4 FINAL DESIGN RESULTS AND EVIDENCE OF ANALYSIS EXERCISE

Evidence from the Engineering Reasoning and Data Visualization assignments were seen throughout the final design projects. Figure 11 shows an open house brochure with an *engineering thinking* process flow chart combining both exercises into one. In this section two examples of design projects are shown to trace remnants of the reasoning and visualization tasks.

Design Process

THINKING PROCESS

Below is a flow chart that shows the thinking process that the group followed in order to end up with their final design. Much time was spent coming up with new ideas, discussing them, and then ultimately deciding whether or not they were reasonable. As a result, the group had to revise many ideas, as well as revisit old ideas when the new ones weren't practical.

Figure 4: Engineering Thinking Process

shelter will help to solve both of these problems, as it will provide a dry place to cook all year round. As well, it will be built in such a way as to provide proper ventilation, and be non-flammable.

Figure 5: Communal cooking shelter.

From the design of the communal cooking shelter, the group discussed ways that it could be improved. It was decided that the inefficiency of cooking over an open fire was a problem, and the group decided to address this problem by designing a cooking stove. Different materials were tested in order to determine which was most suitable for the design, as can be seen in the next section.

Figure 6: Cooking Stove

CONCEPT DESIGN

As can be seen from the Engineering Thinking Process flow chart, the group arrived first at the solution of building a communal cooking shelter. The shelter is designed to solve the problems faced by the people of Changnayili that greatly limit where, and when, they can cook. They aren't able to cook inside due to the poor ventilation and flammable roofs of their huts. As well, they aren't able to cook outside during the rainy season. Building a communal cooking

Figure 11. Engineering Thinking Process

4.1 Design project example 1

In the first example the student group analyzed a community in Tanzania. The group's main finding was an issue with water quality and supply in the village. Figures 12 and 13 (PDF snapshots) show two mentions of access to and retrieval of water in the Engineering Reasoning exercise.

The largest issue affecting the community of Lulanzi is access to clean and fresh water. Even though there is water readily available, it either pools in unclean areas or is a long distance away. The village has a water storage tanks, but the pump used to fill it was stolen. This information cannot be verified however, as the author gives no source or credibility to his statements.

Figure 12. From *important information*: 'The largest issue...access to clean and fresh water'

The primary inference that needs to be made is that the Lulanzi villagers are mostly self sustaining, but need help with their water supply. Even though there is water available, it is reasonable to conclude that water retrieval from the underground springs at the base of the hill the village is located on is too difficult. There is an inadequate amount of water available closer to the village during the dry season.

Figure 13. From *inferences/conclusions*: '...need help with their water supply'

This group included in one of their data visualizations reference to the very first workshop in the project – the root-causes of poverty (Fig. 14). Water was one of the larger categories in all three graphics done by this group. The final visualization was even done as an *iceberg metaphor* visualization emphasizing their focus (Fig. 16).

Table of Data Visualization		
Root Causes and Effects of Poverty in Lulanzi, Tanzania		
Problem	Effects	Root Causes Impacted
Lack of heating sources at night besides burning wood.	Need to gather wood from surrounding area, inefficient.	Health, Shelter, Energy
Runoff from agriculture contaminates groundwater.	Waterborne illness, poor general health, need to travel long distances, and across elevation, to retrieve water.	Health, Water
Inadequate access to clean water in the dry season.		
Lack of sufficient means to store water.		

Figure 14. 'Inadequate access to clean water'

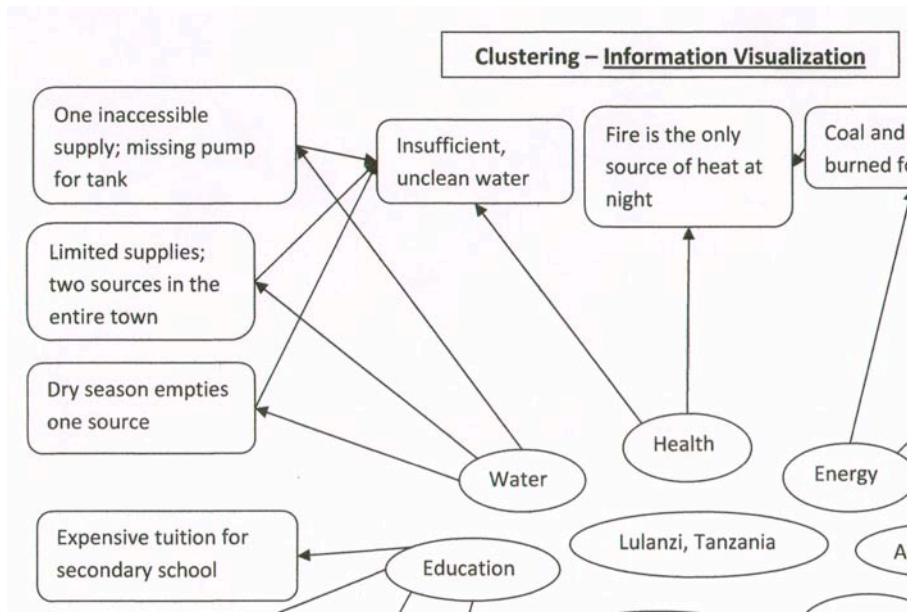


Figure 15. 'Insufficient, unclean water'

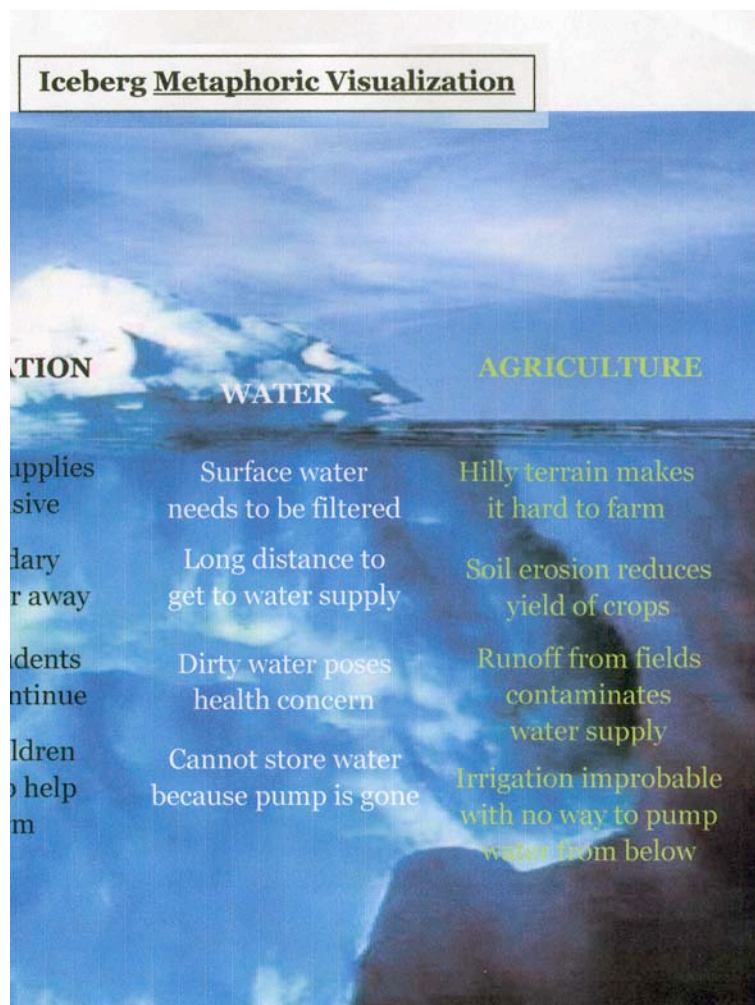


Figure 16. 'Dirty water poses health concern'


In the group's final brochure and open house display a communal rainwater collection system was discussed and a proof of concept model was built. In the brochure (Fig. 17) the students have adopted the idea that "all engineering reasoning requires assumptions" – one of the items on the engineering reasoning checklist.

Providing sufficient clean drinking water

Lulanzi
is a small town located to the south-east of Iringa, Tanzania, which is also the closest city, two hours away.

The issue we decided to tackle is the lack of clean drinking water in the town. Lulanzi previously had a reliable water supply until the pump for the tank provided by the Tanzanian government was stolen, rendering the system useless. Its high elevation lead us to assume that collecting water from down the mountains is of great inconvenience.

Our remedy to this problem is a communal rainwater collection system, established on the local school's rooftop, taking advantage of the large rainfall during the rainy



A type of rainfall collection system[6]

season, which is approximately 1000mm per year[1].

Issues
Corrosion

Our research shows that pure tin forms a nonreactive oxide layer that prevents the tin from corroding or reacting with water. However, this oxide layer was found to react in alkali or acidic environments[5].

Contaminants and Microbes

We assumed that the rainwater is initially free of contaminants. It is our intention not to disinfect the rainwater, as it contains certain types of harmless bacteria that will resist other bacteria that may be dangerous to humans from establishing[2].


Research

Research for this initiative took the form of scientific articles and internet websites, which can be found on the reverse of this paper. Specifically, the research focused on the issues briefly discussed above: the corro-

sion of tin metal and treatment of rainwater for contaminants and bacteria.

Assumptions

A few assumptions were made in designing this system. We assumed that the tank the government provided for the town was above ground and could contain the 840 00 L of water our system could theoretically produce. Another was that the elementary school had 9 000 sq ft of floor space and gable roofs, to simplify the gutters that needed to be built, and said roofs are galvanized with tin. We also assumed that there is access to PVC piping, a major component of the system. Prior to implementation of our rainwater collection system, these assumptions must be verified and changes made, if necessary.



Gable roof; corrugated

Figure 17. Design open house brochure: Assumptions

4.2 Design project example 2

Example 2 discusses a community in Ghana. Again the quality and availability of water was the main topic coming to the forefront in the engineering reasoning exercise (Fig. 18 – PDF snapshot), in the visualizations (Fig. 19) and subsequently in the final design of the student group (Fig. 20).

The author focuses on women's lives in particular. Several precise numbers are used to illustrate the difficulties of local women's lives. For example, women walk 4 kilometers to the nearest borehole to collect water. They can only attend night classes after a 15-hour day of difficult work. Women will walk 4 kilometers with 30 pounds of maize on their head in order to continue to produce income for their families. They will walk 12km further if the maize is not sold.

Figure 18. From *important information*: '...walk 4 kilometres...to collect water'

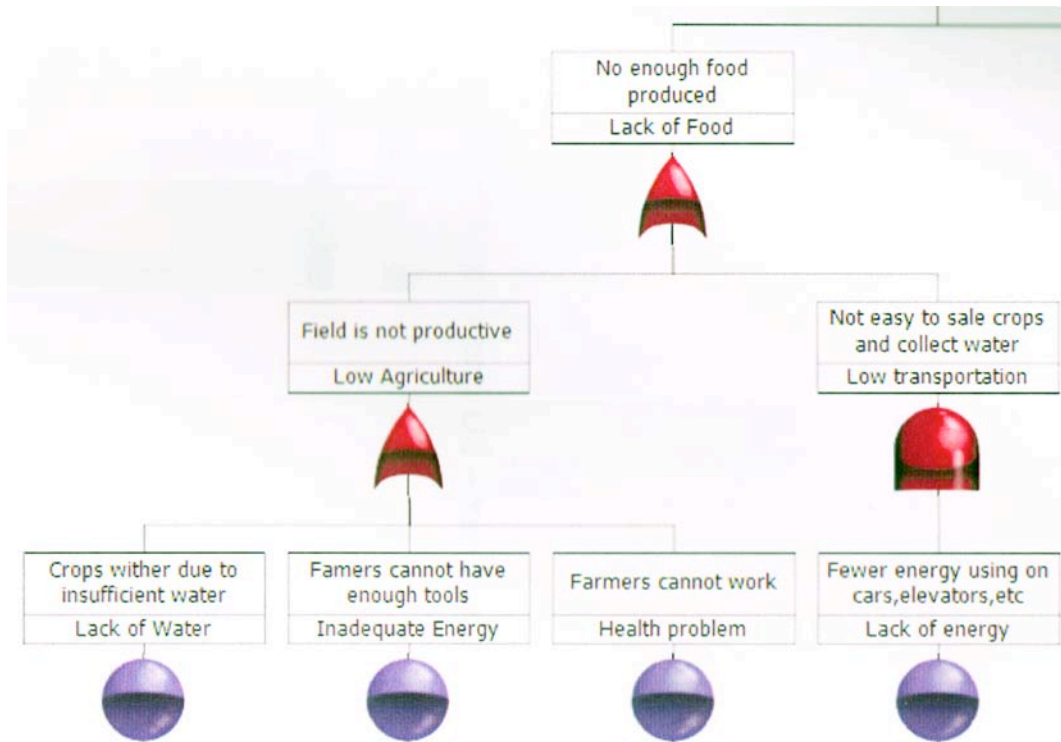


Figure 19. 'Collecting water' and 'crops withering due to insufficient water'

Water Supply and Sanitation in Ghana

Who has access?¹

- Today, 22% of the population have almost no access to safe water
- This number is 30% in rural areas
- Those that do have access often only have it for a few hours a day, or a few days a week

What does "Safe" water mean?²

The WHO has set minimum standards for water which is suitable for human consumption.²

Ghana's natural water supply contains dangerous levels of³:

- Bacterial and Protozoal Diarrhea
- Typhoid fever
- Hepatitis A

Why is this important?⁴

- Access to safe water is a fundamental human need and, therefore, a basic human right⁴
- Unsafe water contributes to 70% of all disease in Ghana⁵
- Diarrhea is responsible for 18% of all deaths of children under the age of five in Ghana – 15,000 children per year¹

Water Sand Filtration

Why Sand Filtration?⁶

Sand filtration works by passing water over the surface of granular material – The higher the surface area of the material, the greater chance of pollutants adhering to the surface. Over a fixed volume the surface area increases exponentially as the average size of the particle decreases.

Surface Area vs. Grain Size per m³

Side dimension of cubic grains (m)	Total surface area of material (m²)
1/9	60
1/5	40
2/7	30
2/5	25
1/2	20
3/5	18
5/7	16
4/5	15
8/9	14
1	13

Why Modular?⁷

Sand filters are in use in homes today⁹, however most are single tank filters and require a very specific grain size. If material within a specific range is not available it must be transported for use in the filter.¹⁰ This is both time consuming and resource-expensive.

Modular systems are adaptable – The surface area can be kept constant regardless of the grain size available by varying the number of trays used.

Ghana is currently experiencing approximately 35% desertification¹¹, suggesting material of varying sizes is available in most areas.

Prototype / Testing Results

How does it function?⁸

Several interlocking, watertight chambers are arranged vertically. Each chamber contains a fixed volume of material. (Prototype: 0.25L/250cm³ in each of three chambers) Water flows from one chamber to another passing through the sand in the process.

As the granular size is known, the surface area per chamber can be determined from the previous table. In this case the sand is estimated to be 0.1mm on average, and roughly cubical. A 1m³ container can contain 10,000 grains per side, so 10¹² grains, each with 6 sides of 10⁻⁹m², so a total of 60,000m². Since 1m³ = 1000L, each chamber contains an estimated 15m² of sand surface per each of three chambers.

Typical Arrangement

Figure 20. Design open house brochure: Modular water sand filtration

5. CONCLUSION

In the examples shown the introduction of Engineering Reasoning and Information Visualization allowed student to get a deeper understanding of communities in developing countries. These two tools showed the real issues and connections in a larger system often overlooked in design projects. Students came up with design ideas that can be seen as interventions 'lower' in the system chain than in previous years, because they were able to understand and see that an improvement to the system early on could make a significant difference to related areas later.

In *The Loss of the Space Shuttle Columbia: Portaging Leadership Lessons with a Critical Thinking Model*, Niewoehner and Steidle write: "The engineer does not work in isolation, but in the context of enterprises, cultures and communities, each of which represents divergent interests and perspectives. Furthermore, no engineer can claim perfect objectivity; their work is unavoidably influenced by strengths and weaknesses, education, experiences, attitudes, beliefs, and self-interest. They avoid paths they associate with past mistakes and trudge down well worn paths that worked in the past [5]." Using Engineering Reasoning as part of this project added a depth to the design work of the students. It also gave the students the confidence and maturity to express their own opinions about the material and make informed design decisions.

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Biographical Information

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Appendix 1 BOP Design

Currently 90% of engineers design for 10% of the world's population. BOP design is engineering and product design for the 4 billion people who live on less than \$2 a day. The following 10 BOP design principles list the many requirements and constraints designers should consider:

“1) Don't just focus on lowering price:

- a. Design labor-leveraging devices in economies where that has competitive value
- b. Local manufacturing with small runs
- c. Poor man's SLA (stereolithography), such as printing with low tolerance 3D printer
- d. Target peoples needs with appropriate technology
- e. Use these markets for piloting new products before scale-up
- f. Don't copy our [own] requirements
- g. Good design comes from knowledge
- h. Redesign the life of the product
- i. Designing for infrastructure
- j. Design to the minimum (focus on needs)

2) Look for hybrid solutions:

- a. Learn how things are sold locally
- b. Some people feel they don't need Internet culture
- c. Technologies not available everywhere and not easily accessed
- d. Infrastructure: hard to maintain/replacement parts
- e. Cost of product caused by location of production
- f. Making something sophisticated may not be the answer
- g. Look for similar cultures for external opportunities
- h. Create leverage by working through government
- i. Combine requirements
 1. Economically viable
 2. Share costs through service
 3. Fills compelling need

3) Plan for cross-cultural portability:

- a. Design becomes rural within geographic context of end user
- b. Rework inside of computer to use alternative source of power
- c. Fundamentally multi-cultural “uncommon place”
- d. Branding: customer relations
- e. Create meaningful product ingredients and building blocks
- f. Alternate demographics are market fragments

4) Reduce, reuse, recycle:

- a. Cradle to cradle
- b. Lower labour costs to make repairs worthwhile
- c. Use students to replace tools
- d. Collaborative, participative process

5) Deskilling work is critical:

- a. Create a new architecture for education
- b. Leverage relationships with government

6) Develop new approaches to customer education:

- a. Product that teaches a skill (local activism)
- b. Familiarity with user
- c. Teach a marketable skill (read, write, etc.)

d. Help [BOP customers] to start/maintain a business of their own

7) Products must work in hostile environments:

- a. Different environmental criteria
- b. Prosperity can create a hostile environment
- c. Protect ideas; allow ideas to prosper

8) Don't assume technological literacy:

- a. Understand what [BOP customers] are trying to accomplish
- b. Make it familiar in form and function
- c. Single purpose vs. multi-purpose
- d. [There are no 'dumb users', only dumb products]
- f. Simplicity
- g. Framing the world in terms of how [BOP customers] understand it
- h. Remote, indirect communication
- i. Learning curves may be inappropriate and technological literacy means different things to different people
- j. Simple function, simple to operate (evident), minimal maintenance

9) Rethink distribution:

- a. More localized manufacturing
- b. More modular products
- c. Supply products that are raw materials for local designers
- d. Self-distributing caused by needs
- e. Sustainable livelihoods, sustainable business models

10) Expect technology leapfrogging:

- a. Technology requiring little infrastructure
- b. We must understand [BOP worlds]"

Sources:

<http://compassioninpolitics.wordpress.com/2009/02/06/design-for-the-bottom-of-the-pyramid/>
http://www.12manage.com/methods_prahalad_bottom_of_the_pyramid.html

Appendix 2 Student responses to the Engineering Reasoning checklist

MAIN PURPOSE

The main purpose of this engineering article is to introduce a small village named Changnayili in Ghana. The author focuses on five areas to describe the living conditions of the Dagoomba people, one of the major groups in the Northern Region. The author portrays the Dagoomba people living in poverty by describing their culture, geography, socio-economic conditions (including education), living conditions and energy sources. In each part, the author also lists some challenging problems that these people face.

KEY QUESTION

The key question that the author is asking is “How do the Dagoomba people live on a day-to-day basis given the limited resources?” The author addresses this question by first describing the geography and climate of the region (Section 1.2). This provides a base where the reader then forms the conclusion that due to the lack of fertile land, crops are hard to grow, income is low, and the dry season is the leanest of seasons because of food scarcity. The author then describes how the members of the village function to survive: women work 15-hour days to-and-from water sources, grinding mills and firewood/charcoal sources to ensure their daily tasks are completed; and sources of income are yam, rice and groundnuts. While poverty is a main theme in this article, the author also states that while education is low in the community, some are still willing to learn despite their hardships.

MAIN ASSUMPTIONS

As informal and open as this document is there are many things left to question. It would appear there have been several assumptions made on the author's side. The first is the assumption that the countries donating secondhand clothes are rich. This has not been based on any real fact. It is certainly verifiable that the clothes are being received from countries that are able to spare them. This however does not establish any basis to assume an economic position of the donors. If somebody is charitable enough to donate a kidney, it doesn't mean they have lots more to spare. Many struggling countries try to reach out to others through donations of clothing and other such items.

A second assumption arises in the second section. There is mention of a rainy season and a dry season. Then the document refers to a dry wind that arises in the dry season for a whole month. It is interesting that the wind was described, which has nothing to do with the rest of the document, and for some reason precipitation levels and expectancies are not mentioned. It is as though we are to know what precipitation levels they receive annually. It did not paint an effective picture of their situation. If farming and water use are being mentioned throughout the rest of the document, why is precipitation not even mentioned?

There exists a third assumption in the latter parts of the document and it is developed throughout the entire document. The roles of women are well described; their challenges and daily work are brought completely out of obscurity. The readers have a window that offers a clear view of the daily lives of the Dagoombian women; however, the roles of men are rarely mentioned. It is as though the readers are to understand the women do everything and the men have several wives and their roles are the same as

anywhere else. Or, perhaps we are to understand that the men do very little and the women do all the work and that there exists a gross inequality between the sexes.

POINTS OF VIEW

The main point of view that the author is presenting in this article is that the Dagoomba people live in poverty and that its women are constantly doing the majority of the tasks to keep the village running. By highlighting the roles of the women in this community, the author touches upon gender inequality and its consequences to the village. Therefore, this article is mainly presented from the point of view of the Dagoomba women. It is also presented from the point of view of the author, who is not only empathetic to the Dagoomba people but is also a participant of Engineers Without Borders, which is an organization that aims to improve standards of living in several African countries. Therefore, the author is empathetic and sympathetic to the people of this village. Another point of view the author presents is from the empathetic reader's point of view. The author presents the article in such a way that marks the gaping differences between the reader's living conditions and those of the Dagoomba people; this draws the attention of this particular reader and attempts to persuade the reader to provide or send aid in some way.

IMPORTANT INFORMATION

One piece of important information found within the text is the sense of community these people hold. They hold strong ties within their families as well as a large community. They help one another even though they possess little themselves. Culturally, the majority of the villagers are Muslim though there are other religions present but to a lesser extent. There is charity work being done in the area as most of the villagers wear second hand clothing received from rich countries. The land is generally flat but is being cleared at a fast rate. Some crops can no longer grow unless fertilizer is supplied and in other cases some of the crops cannot even grow with fertilizer. Animal life is diminishing in the area. Two main seasons are present the rainy season and the dry season. During the end of the dry season the water supply found in the dam 1.5km away dries up. The crop grown often is Maize and is eaten three times a day. This is their only source of nutrition as they sell any other crops grown at the market. Most children present do attend primary school but the majority of the children do not pursue school any further than this as the secondary school is located too far away. Women do attend night classes 2 hours a day three times a week after working 15-hour days. Every bit of work is done manually and the only method of transportation is walking. They live in small huts that are arranged in a manner so each family is located together. Most work is done outside of the huts; the villagers only rest and sleep within the huts.

KEY CONCEPTS

One of the key concepts we need to understand in this article is poverty. Poverty is the condition where an individual or a group of people have insufficient or little amount of money, have little or lack of food and goods and have substandard or poor housing. This theme is the undercurrent of the author's article, where s/he describes the constant and daily struggle of Dagoomba people to survive. For example, the author states "food can be pretty hard to come by towards the end of the dry season." A sub-concept we must understand is that, as the reader(s), we must realize that we are the more fortunate and richer party. The author presents the article in such a way that it is to be read by a person who lives in a first-world country. Therefore, the author markedly expresses the vast differences between those living in countries like Canada and those living in Ghana.

The second key concept we need to understand is that poverty causes hardships. This is evident when the author states, as an example, "the land is degrading in many areas and people are no longer able to grow certain crops without fertilizer" (Section 1.2), and s/he also states that "the community lacks basic drainage and sanitation facilities." Because hardship stems from poverty, the author means that if there was sufficient income, fertilizer could be bought so that certain crops can be grown, and s/he also implies that drainage and sanitation facilities could be installed to improve the standard of living in the village.

Another key concept we need to understand is the suppression of gender equality in this community. By this idea, the author states numerous times (Sections 1.1, 1.3 and 1.5) that women have the hardest and most strenuous roles and tasks, while in comparison, it is implied that men do not seem to provide much for the families nor do they perform an equal amount of work to relieve women from their daily 15-hour chores. Thus, the author, by way of presenting her/his observations about each gender's roles (primarily women's roles), is stating that gender inequality exists in this community.

A fourth key concept is that education (primary and secondary), as well as access to education, is essential for progression. In this article, the author rationalizes that "education is low in the community (Section 1.3)." The author reasons that this is due mainly to the low accessibility of education to the community, as the closest schools are 16 km away.

Also, we need to understand is that machines, electricity and modern infrastructure and transportation, both of which provide accessibility to water, goods and education, play enormous roles in maintaining successful and healthy communities. By this idea, the author means that the lack of all these "essentials" leads to a poor community, where its inhabitants depend upon seasonal farming for food and income, walk long distances to obtain water and process maize, and struggle to meet their educational needs.

In addition, we must understand that money provides food, shelter and clothing. From this key concept, the author means that the lack of or an insufficient amount of money, as we see in this article, leads to a low standard of living. As farming is the only source

of income for families in Changnayili, this is a highly unstable source of income as it is dependent upon the season.

Finally, we must understand the key concept of time and its value. For the Dagoomba people, especially the women, the author states that the women work 15-hour days and yet some still find or make the time to progress in their education (by attending a two-hour night class three times a week to learn to write the local language). We must understand that time has one meaning to us as readers from a first-world country but a completely different and deeply consequential meaning to those living in third-world conditions. The author brings up the value of time again and again throughout this document. For example, the women must walk a certain distance to the nearest grinding mill to husk the maize, which may take at least one hour one-way. If the mill is not operational, they may spend up to three hours one-way making the trip to Tamale to reach a working mill. Moreover, they must obtain water, which again takes a large amount of time. They also must spend time in the fields and process shea nuts by hand, as well as spend another two hours to bring back firewood or charcoal. Therefore, we must understand that the lack of or improper use of time has great and grave consequences to these people's survivals.

7.0 IMPLICATIONS

- a) Readers are able to make assumptions of the existence of assumptions made by the author. Through this method we compile an interpretation of things that are not mentioned. If we take this entire document seriously, accepting it all as 100% indisputable fact and dwelling upon the assumptions we feel the author has made, we can paint a picture for ourselves that may be more fiction than fact. For example following the above mentioned assumptions a reader may assume that the Dagoombian men are lazy and that they do very little. A reader may assume that these men have no respect or love of their families. A reader may assume that life is so hard in this area due to the lack of men's participation. Since it has been mentioned that more boys go to school than girls, what do the boys do with their education? A reader could read this document loathing the Dagoombian men when, in reality, they may have imagined a nonexistent problem.

Taking this document seriously, a farmer or any reader experienced in agriculture may assume that based upon the lack of mention of precipitation and mention of fertilizers and barren soil and degrading soil, that the Dagoombian people are using the wrong fertilizers and scorching their soil. They may paint a very bleak picture of the capabilities of these people in agriculture, when the fact may very well be that they are excellent farmers. Perhaps a reader may assume that these people are not properly utilizing the amount of precipitation to their advantage.

A reader may feel offended based upon the assumption made that all donating countries are rich. They may walk away feeling some resentment of the Dagoombian people. There are mainly negative externalities to be taken from assumptions and this could hurt the subjects of the article more than it could help them. There are exceptions in assumptions that promote a seemingly innocent oversight that over-glorify a certain topic that promote positive externalities. These are mainly used in marketing and are not seemingly present in this document.

- b) If we fail to take these implications seriously we may underestimate a real existing problem that a reader is or was to assume from reading the article. Perhaps these assumptions were to be picked up. Perhaps the mentioning of *rich*, donating countries is to release some tension the author has inside caused by their feeling that the "rich" countries do very little for them.

Perhaps in not mentioning the rainfall the author wanted the reader to assume that rainfall is negligible, and therefore their situation is more desperate that it has been made to seem. Perhaps the scarcity of mentioning the men's roles was the cry for help in an unfair patriarchal-dominated society.

DEVELOPING UNDERGRADUATE PROJECTS IN MULTINATIONAL TEAMS TO ENHANCE EMPLOYABILITY

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ABSTRACT

Our society is experiencing sudden changes in work organization in part due to the growing ease with which people can collaborate. Many successful cases of peer-to-peer models of organization arise and assume leading positions in world economy replacing, in many cases, the traditional hierarchical organization. People are evolving and interacting within heterogeneous teams composed by members from many different cultural groups and with distinct skills and backgrounds. Modern economy requires engineers to excel in collaborative and communication skills at an international setting. However, these competences are not usually addressed in most engineering curricula. We believe that in such a demanding and culturally diverse environment as the labour market is today, it is essential to promote team work and communication skills at an international and intercultural level. In the Multinational Undergraduate Team Work course, MUTW, students develop their capstone project as members of an international team while working at their home institutions. MUTW projects are to be developed by teams of final-year-undergraduate students from a multinational group of higher education institutions working to solve some engineering problem. Team members are geographically spread to assure heterogeneous teams and to promote international cooperation. This paradigm can be applied in any project/internship course unit. The results from the first edition are very encouraging supporting our initial hypothesis that MUTW significantly promotes students soft skills without requiring any change to prior degree curricula.

KEYWORDS

Employability, soft skills, capstone course unit, curriculum development.

INTRODUCTION

Recent results from the European Association for Education in Electrical and Information Engineering network [1] point out that students complain about a big gap between what they would like to know and what is taught at school related to the ability to work in an international context.

On the other hand, the Association for Computing Machinery (ACM) and the Association for Information Systems (AIS) have recently revised a model curriculum for undergraduate degrees in Information Systems [2]. This model identifies leadership, collaboration and

communication as foundational knowledge and skills required from information systems graduates.

Modern economy is highly dependent on technology requiring engineers to excel in collaborative and communication skills in international settings [3]. However, these competences are not usually addressed in engineering curricula.

Students' motivation and enthusiasm is another fundamental aspect requiring our attention. There is a big gap between the environments where students perform schoolwork and other activities. General activities involving students outside the academy are much more engaging and immediately rewarding than academic tasks. This gap suddenly got bigger with the advent of the web and mass collaboration. This is probably one of the reasons lying behind students' lack of enthusiasm and motivation for schoolwork [4].

Our society is experiencing sudden changes in the way people and institutions produce and manage value. Many successful cases of peer-to-peer models of work organization arise and assume leading positions worldwide. Take the cases of Linux, Wikipedia, InnoCentive and the Human Genome Project, for instance [5].

People are developing and interacting within heterogeneous teams composed by members from a lot of different cultural groups and with distinct skills and backgrounds but these issues are not generally addressed by engineering curricula. We believe that in such a demanding and culturally diverse environment as the professional world is today, it is essential to promote team work and communication skills at an international and intercultural level.

Developing curricular activities involving students from different countries, collaborating to complete projects that generate relevant outputs to the community might improve students' enthusiasm as well as their teamwork and communication skills. The Multinational Undergraduate Team Work project (MUTW) (see <http://www.mutw.eu>) presents a proposal that might come to fill the existing lack in this area.

Our hypothesis is that MUTW promotes students soft skills and, as a consequence, their employability, without the need to change curricula, just by applying a more effective paradigm than the traditional project/internship model.

The MUTW project is devoted to the creation and management of international teams of students who will collaborate in order to develop a solution for a given engineering problem. MUTW courses are developed by a group of higher education institutions working as a team. Final-year-undergraduate students from the partner institutions are the target of our project. Under MUTW, these students are engaged in the development of a common project, each partner being responsible for only a part of the final product.

By the end of their graduation, engineering students have to develop some project within a generic project course unit; MUTW replaces that course unit for those students who decide to cope with the project.

Taking the above mentioned aspects into account, MUTW generally intends to prepare students for an emerging economy based on active (mass)collaboration while increasing their enthusiasm and motivation for schoolwork.

The main results from the first edition of the MUTW course point out the benefits of this innovative project course unit. Students recognize that team work skills are improved mainly due to the academic outcomes of MUTW. The innovative aspects of the MUTW project

execution as well as the chance to profit from an intercultural exchange of experiences both contribute to improve students' communication skills in an international environment.

In the rest of the paper we will review MUTW background then we will briefly describe the MUTW methodology. The results from the first edition of the MUTW course are presented just before the conclusions which will be provided in the last section of the paper.

BACKGROUND

The international guidelines for education expressed by Jacques Delors in his report to UNESCO (1996), enclose four pillars of education for the twenty-first century: learning to know, learning to do, learning to live together and learn to be. These embody important dimensions of formation of the person as an individual and citizen, and form a set of principles that, once accepted, may help to overcome traditional views of a purely instrumental education. The main objective of the Bologna Process proposals is to create a European area of mobility of teachers, students and to improve the employability of graduates. The first studies stressed that the so called knowledge society should be supported by their institutional and human resource whose quality levels should increase in a solid and progressive manner. Quality and efficiency are essential goals to the construction of a European area of education and training [6]. In Portugal, with more than 10 years after signing the Bologna Declaration, it is evident how the higher education institutions have sought to adapt to new requirements of this European Higher Education Area (EHEA). Providing training courses that are more than sets of disciplines and promoting academic experience scenarios in which students actively participate in the construction of their training, thus stimulating self-learning, has been perceived as necessary to achieve the high standards of the EHEA. The efforts of Higher Education Institutions (HEI) should be focused on setting and providing environments where students can learn in an active fashion.

Considering the vocational development as a continuous process occurring throughout life as well as the analysis of the adjustment process as a product of dynamic interactions between individuals and contexts, together with the consideration that the higher education objectives are fulfilled by the students' complete training, lead us to the need of taking into account the personal and contextual factors that may be behind the higher education career adjustment. Lent, Brown & Hackett [7] defend that the focus of the adjustment study should be put in the social conditions that shape the learning opportunities, which students are exposed to in interpersonal relationships (e.g., those of support and indifference), and in the results anticipated by the individuals according to their choices, involvement and persistence in certain activities.

The Bologna process has become a paradigm of the European higher education. It is undeniably the current engine propelling discussion about the European higher education. The Bologna process has polarised the debate and the search for solutions to problems that had been piling since the previous decade. Among these problems it is to be referred, for example, the maladjustments to the work demands in the knowledge society, the funding decrease, the strictness of the system suffering from lack of diversity and adjustment capability, lack of competitiveness, inefficiency of the relations with society, and scholar failure. The success of the EHEA depends on the students' effective mobility as well as on the quality generalisation of the training proposals at the European Union scale.

It is of extreme importance to think of strategies to support the teaching community that enable to question and to understand the learning and the pedagogical mediation problems. These strategies should be more centred in the learners' projects and less in the transmission of contents, which refers to the valorisation of the analysis and comprehension processes of the pedagogical methods and of students' learning processes (cf., for example,

[8]). Based on the self-efficiency and results expectations, and on personal objectives, the authors of the career socio-cognitive theory have explained the influence of school and of the peer group in several aspects of the vocational development. They affirm that the peer group is a relevant source of information in building meaning around the roles given in shaping, evaluation, performance and merit, contributing for the development of the individuals' vocational interests and values.

Several theories assume that the work satisfaction depends on the degree with which individuals understand that their work environment provides a favourable set of conditions (e.g., [9]) or a set of enforcing elements consistent with their working personal values (e.g., [10]).

The comfort models articulate the academic and professional objectives with the other life roles and tasks [7,11], as it's the case of the role of the student in academic work teams.

Brooks and Dubois [12], Felner and Felner [13], Terenzini and Wight [14], in the scope of the student's adjustment to higher education, defend that simultaneously with the students' competences to face the higher education challenges, the quality of the adjustment is strongly associated with the social supports and with the resources made available by the peers. In the last decades, the theoretical and empirical developments around the social support have enabled to define, understand and detail the role of perception and of the social support as a strongly predictive factor of well-being [15,16] and of individual adjustment [17,18,19]. The perception of the social support names the expectations that there will be a basis or support if we need one [20]. This has revealed to be a mediator factor of the impact of the troubling or adverse situations in the physical and emotional well-being [16].

Although we don't want to be too exhaustive, we believe to be relevant to state that the theoretical body on which MUTW is sustained include such diversified domains like elaborating the globalising models for studying groups' internal dynamic (e.g.,[21,22]), namely by analysing the value of peer interactions and the way these are processed in the different types of groups (e.g.,[23,24,25]) or by observing the mutual help processes (e.g.,[26,27,28,29]); studying their effects on different psychological variables (e.g.,[30,31,32,33]); using cooperative learning as a tool to reduce scholar conflicts (e.g., [34,35]) and to promote social inclusion (e.g., [36]); training the teaching and non-teaching staff for cooperative work and for the creation of schools as communities of individuals who learn by cooperating (e.g.,[37]).

In the scope of MUTW, our proposal is to lead the participating students to work based on the team work assumptions. The team research was proposed by [38]. The team research presupposes that the students are the ones to determine what they should learn and how to do it, considering the learning capabilities of each team member. As the authors refer, "the goal of this organization is to create conditions to allow students, in collaboration with their peers, to identify problems, plan together the procedures needed to understand and cope with these problems, collect relevant information, and cooperatively (though not necessarily collectively) prepare a report of their work, usually in some creative and interesting way" [38].

Schlossberg, Lynch and Chickering [39] point out the social resources in general and the social support perception in particular as facilitating elements of the individuals' social and personal adjustment, and defend that the students' vocational success depend a lot on the level of concern they perceive from the others and on the fact of being, both as student and person, valued and protected. Astin [40] also affirms that the larger the amount and the quality of the students' investment in the diverse experiences related to the academic life, without excluding the relational and social aspects, the more possibilities those students have of being successful in their education and professional life. This way, and according to these authors, it is advantageous for the student to believe that the others care about him,

value him and accept him, and at the same time that they are there to help him solving problems and overcome difficulties in case he needs. Cutrona and collaborators [41], in researches within the area of the social support evaluation in higher education context, identified the social support made facilitated by the peers as a predictive factor of the students' academic productivity, as regards their average grades, controlling the academic aptitudes and the conflicts between peers statistically [42]. On the other hand, in a study developed with higher education Portuguese students, Pinheiro and Ferreira [43], showed that perceiving the social support may be an important condition for the student's general well-being.

It is our belief, in accordance with the empirical literature and research of reference in the area, that the existence of satisfactory interpersonal relationships and the perception of a solid social support may be facilitating elements for the academic personal and social adjustment of the individuals in a specific context [39,41,44,45].

Therefore and in conclusion, the literature review here explained, allows us cite as relevant the purposes of our project. Of all our purposes, and according to the literature review outlined here, we conclude as being highly pertinent to foster the improvement of employability and communication skills of higher education students, through the systematic and deliberate monetization of teamwork.

MULTINATIONAL UNDERGRADUATE TEAM WORK

The MUTW methodology is devoted to create and manage international teams of students who will collaborate in order to develop an engineering problem. For the first editions of MUTW this was a software system. These teams are set up for a semester with the purpose of developing and presenting a solution to a given engineering problem. For the first editions, running during 2009/10 and 2010/11, students from 11 HEI from 9 different countries have been organized in two teams: the Orange team has twelve students, two from each of six institutions, and the Blue team has ten students, two from each of the other five institutions.

The problem specifications, its architecture, its main building modules and interfaces will be briefly described by the consortium – at this stage, only the central rules are provided; students have to interact and cooperate during the semester in order to agree on the other necessary specifications. At the end of the project all modules must be integrated and the fully operational system, a unique product, will be presented by the students as a team.

Each team member will be responsible for: (a) developing a part of the whole solution, (b) justifying their technical options as an integrating part of the whole solution proposed by the team, (c) collaborating whenever needed with other team members, either from their own team or from another MUTW team, to guarantee that problems are solved in due time, and (d) that all parts integrate into a unique final solution.

The team as a whole must: (a) guarantee that all parts integrate well to produce a unique solution for the problem, (b) produce a unique report describing the full solution and (c) present the full solution to the project jury. The project jury will be composed by a teacher from each partner institution.

Partner institutions are responsible for: (a) selecting students for the team, (b) defining a supervisor and (c) following, guiding and evaluating students.

The MUTW methodology is being reviewed based on the experience of the first year. Nevertheless, the preliminary version can be viewed in detail [46].

EVALUATION

One of the main concerns of the MUTW project is to tune up a methodology that might be used in the future by any HEI wishing to setup a MUTW-like course. Monitoring students and their progress throughout the semester and at their final evaluation is a main activity in the MUTW Multilateral Erasmus project providing very valuable information which is essential for tuning the MUTW methodology.

We have collected data from several distinct sources, during the first pilot edition of the MUTW course unit, held in the Spring semester of 2009/2010, including: students' feedback form, students' final grades and grading criteria, assessment questionnaires from the base competences seminars and usage statistics from the groupware platform.

After attending the kick-off meeting students provided their comments on the meeting and filled in online questionnaires, through the MUTW Moodle platform, to evaluate both base competences seminars. These questionnaires were focused on the evaluation of the seminars' quality and its relevance to students. The results from the analysis of this data were used to improve the content of the seminars and also to adapt the organization of the kick-off meeting to comply with the need to have students spending more time working in their team than in instructive activities like the seminars.

The usage statistics provided by the online tools supporting the communication among team members, the management of teams and the development of the final product were used mainly to confirm students' commitment to their team. This data merely confirmed our perception as obtained from students' supervisors as well as from the students themselves.

Students' grading in MUTW is performed by an international jury and is based on a set of criteria previously defined by the MUTW consortium. Students' grades are, in part, due to the quality of the course and to the extent to which students feel keen on it. From this point of view, this data also contributes to evaluate the quality of MUTW as a course unit.

The students' feedback form is a questionnaire that students fill in, together with a peer evaluation form, at the end of the MUTW course just after their final presentation, while the jury is deliberating on their grades. The students' feedback questionnaire has several multi-choice questions as well as open questions for students to provide their comments on MUTW. The peer evaluation form allows students to provide their opinion regarding the commitment of their team mates and on the global performance of their team.

The core data used in the current study comes from these last sources: student feedback form, peer evaluation form and student grades.

Student grades

Students from MUTW come from different HEI with different grading scales. The final grade that a student gets from the MUTW course is conforming to the scale in Table 1. The way these grades are then converted to their home grading scheme is a concern of each institution.

This final grade is a weighted mean of several criteria assessing several competencies that are promoted in MUTW courses. For the first edition of MUTW these criteria have been organized in two groups: one group, with four criteria, assessing the project as a unique product delivered by the team and another group, with two criteria, assessing individual aspects of student's performance. Each of these groups stands for 50% of the student's final mark (see Table 2). Mean students' grades by team are presented in Table 3.

Table 1
Students' Evaluation Scale

<40	Fail
40-50	Pass
50-60	Fair
60-75	Good
75-90	Very good
90-100	Excellent

Table 2
Assessment Criteria

Weight	Apply	Evaluation criteria
10%	Team	(A) Base competences seminars
20%	Team	(B) Product, process
10%	Team	(C) Report
10%	Team	(D) Presentation
25%	Individual	(E) Management competence within team
25%	Individual	(F) Supervisor opinion

Table 3
Mean Grades Per Team

Weight	Apply	Evaluation criteria	Orange team	Blue team
10%	Team	(A) Base competences seminars	95	95
20%	Team	(B) Product, process	90	98
10%	Team	(C) Report	95	85
10%	Team	(D) Presentation	80	90
25%	Individual	(E) Management competence within team	83	84
25%	Individual	(F) Supervisor opinion	82	93

It's clear from Table 3 that students performed very well. This is an important observation supporting our hypothesis that the MUTW paradigm is attractive to students and motivates them. Although we have no control group to compare these figures, we can confidently claim that these grades are above the average in common Project/Internship courses at our own institutions.

Peer evaluation

After the end of the MUTW course, once the final presentations from both teams have been concluded, students filled in the peer evaluation questionnaires.

The peer evaluation questionnaire has three parts:

1. One for students' appreciation regarding the global team results,
2. One for students to provide a mark for each team member, including their own, and
3. An optional open question where students are free to give their opinion upon any team member.

Our analysis was based only on parts 1 and 2.

In part 1, students are asked to grade their own team results, on a scale from 0 to 100, on the following aspects: Analysis, Development, Integration and Test. Figure 1 show the comparison between both teams regarding their perception on their own work.

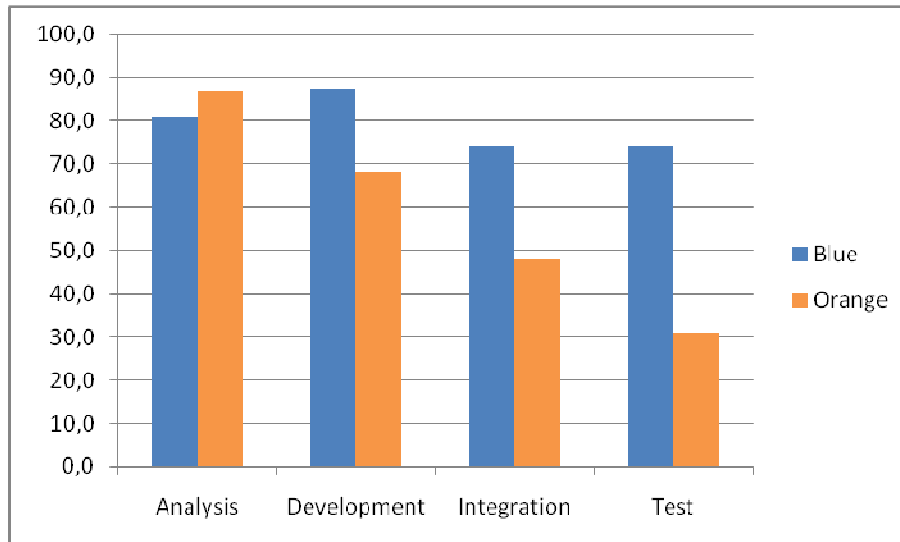


Figure 1. comparison of team performance as perceived by team members

The Blue team seems more confident on their performance than the Orange team. The fact is that the Blue team was able to present a product running online while the Orange team presentation didn't go that well.

One of the main reasons for this fact is probably related to both teams' dimension. The Blue team is smaller – there are 9 members in the Blue team and 12 in the Orange team – and, therefore, easier to manage, mainly taking into consideration the lack of previous experience from students in managing international project teams.

Part 2 of the peer evaluation questionnaire is devoted to grade individually each team member, including the student who is filling in the questionnaire himself. Students are graded in two distinct indicators: percentage of participation in project, on a scale from 0 to 100, and motivation, on a scale from 1 to 5 (best).

The aggregated results on participation for the Blue team members are presented in Table 4 while those for the Orange team are presented in Table 5.

Table 4
Member Participation in Blue Team as Perceived by Peers

Student	B1	B2	B3	B4	B5	B6	B7	B8	B9
Mean %	14,6	10,3	14,6	14,6	11,7	10,0	11,7	0,9	11,7
StdDev	2,7	2,6	2,7	2,7	1,4	2,9	1,4	2,3	1,4

Table 5
Member Participation in Orange Team as Perceived by Peers

Student	O1	O2	O3	O4	O5	O6	O7	O8	O9	O10	O11	O12
Mean %	4,0	10,7	3,9	12,4	6,7	10,6	10,6	3,5	6,7	12,9	11,4	6,5
StdDev	2,9	1,8	2,7	3,6	4,0	3,2	3,6	3,3	3,9	3,8	2,9	3,3

Students' motivation (Figures 2 and 3) is another indicator of the benefits of the MUTW paradigm. In the Blue team we observe a high level of motivation in the generality of the team members. In fact, six out of nine have been granted a maximum motivation level (5

points) unanimously. Only one student, the only one that failed MUTW first edition had a low level of motivation.

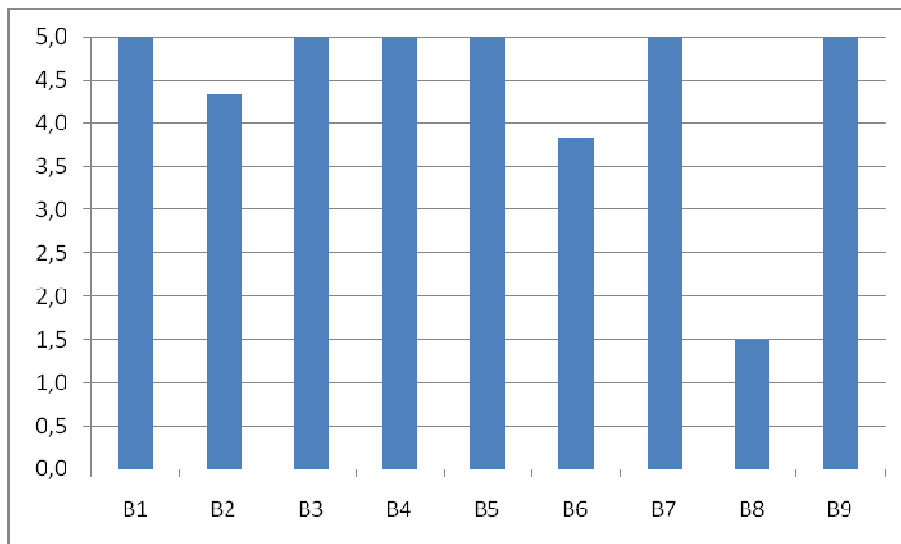


Figure 2. Blue team students' motivation

In the Orange team we can identify two groups (Figure 3), each one with six students that have clearly distinct motivation levels. This pattern was also obvious from students' behavior during the last project meeting when students were concluding the final arrangements for their presentations. In the Orange team there was one group of students working hard to conclude their tasks while another group was not that enthusiastic.

We have noticed that some of the MUTW students in the first edition were not being credited for their work in MUTW. Although this is a scenario that shall not happen in the future, it might have been one of the main reasons for low levels of motivation. Students that are moved by extrinsic motivations, highly indexed by their ECTS credits, need this incentive to feel committed. It was however interesting to notice that some students were moved by intrinsic motivations and that MUTW provides these incentives to students.

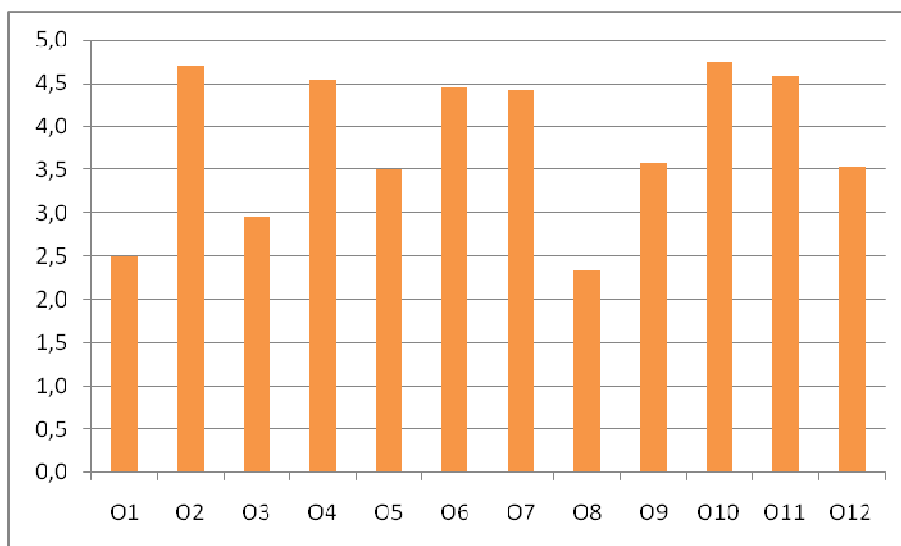


Figure 3. Orange team students' motivation

Tables 6 and 7 reveal that, as expected, there is a very strong correlation between students' motivation, their participation in the team and their final grade. This is particularly obvious in the Blue team.

Table 6
Correlation Between Student Participation, Motivation and Final Grade in the Blue team

	Participation	Motivation	Final grade
Participation	1		
Motivation	0,95	1	
Final grade	0,97	0,99	1

Table 7
Correlation Between Student Participation, Motivation and Final Grade in the Orange team

	Participation	Motivation	Final grade
Participation	1		
Motivation	0,97	1	
Final grade	0,82	0,80	1

Student feedback

The student feedback questionnaire is the most informative and most relevant tool for the evaluation of MUTW. We have collected data from the 18 students who have filled in the questionnaire. This questionnaire collects students' feedback on 33 variables (Table 8).

Linear regression analysis

The student feedback questionnaire has 33 variables each being evaluated by students from 1 (worst) to 5 (best). We have decided to reduce the number of variables to analyze, discarding the less relevant ones. From all the 33 variables we have discarded 12. 21 variables remained to be analyzed.

From the remaining 21 variables, 7 were considered as target/dependent variables, given our goals, and the remaining 14 were viewed as independent variables. Dependent variables (G, 5n, 5m, 5l, 5k, 5j and 5i) were analyzed one at a time.

Missing values have been replaced by the respective variable average rounded to unit.

Linear regression models have been generated for each dependent variable. From these, only the 5i model is significant at 10% significance level. These regression models have been computed from a sample with 18 examples and 14 independent variables.

To improve regression quality we have tried to reduce the number of independent variables to the ones that seem more important. In a second try we have used 5 independent variables to predict five distinct targets. From these 5 regression models only 5m and 5l are significant at 5% significance level. However, these are precisely the outcomes we are really interested in (5m - team work skills and 5l - communication skills in international setting).

The model on 5m presents a determination coefficient, R^2 , of 75% while the one on 5l is 59%. In the 5m model only the variable 5a - Academic outcomes of MUTW is significant at 5% significance level.

Table 8
Students' Feedback Variables

2a - Project assignment
2b - Duration of the MUTW meetings
2c - Subjects of the MUTW seminars
2d - Groupware platform
2e1 - Motivations: Academic
2e2 - Motivations: Cultural
2e3 - Motivations: Practice of foreign language
2e4 - Motivations: Friends living abroad
2e5 - Motivations: Career plans
2e6 - Motivations: European experience
3a - Support of MUTW consortium
3b - Support of home institution
4 - Academic recognition
5a - Academic/learning outcomes of the MUTW
5b - Innovative aspects in the project execution
5c - Interdisciplinary elements
5d - Personal outcomes
5e - Chance to profit from an intercultural exchange of experiences
5f - Benefits from individual skills of team members
5g1 - Seminars: hours taught
5g2 - Seminars: teaching equipment
5g3 - Seminars: capabilities and expertise of the professors
5g4 - Seminars: overall quality of teaching
5g5 - Seminars: expected learning outcomes
5g6 - Seminars: work sessions besides the seminars
5h - Serious problems during the MUTW
5i - MUTW will help in further studies/career
5j - MUTW helped improving creativity
5k - MUTW will help in finding a job
5l - MUTW improved communication skills in an international setting
5m - MUTW improved team work skills
5n - MUTW improved European feeling
G - Overall evaluation of MUTW

The model on 5l has two significant variables at 5% significance level. These are 5b - Innovative aspects in the project execution and 5e - Chance to profit from an intercultural exchange of experiences.

This led us to conclude that:

1. MUTW improved team work skills (5m) due to Academic/learning outcomes of the MUTW (5a)
2. MUTW improved communication skills in an international setting (5l) due to the Innovative aspects in the project execution (5b) and the Chance to profit from an intercultural exchange of experiences (5e).

Cluster analysis

Cluster analysis relate to grouping or segmenting a collection of objects into subsets or clusters, such that those objects within each cluster are more closely related to one another than objects assigned to different clusters. There are two major methods of clustering --

hierarchical clustering and k-means clustering. We have applied both to group students and also to group the variables under analysis with the goal of perceiving patterns in both views. All the computations required by the cluster analysis have been performed with the support of the statistical software tool SPSS 17.0.

In short, the main settlements from cluster analysis let us highlight the following aspects:

- a) The student's project overall evaluation seems to be consistent and agree with the evaluation of specific aspects.
- b) Some students had particular problems with the project but, that does not appear to have hindered neither its overall nor its partial evaluation.
- c) Standing out positively, the support given by home institutions and the opportunity to profit from an intercultural experience, which has been exposed in a comprehensive way, by all students.
- d) According to the number of clusters considered, the influence of geography also suffers variations. Opting for a smaller number of clusters seems to show the existence of a relationship between satisfaction and geographical location. With the consideration of a greater number of clusters, only one group of students from the same institution belonged to the same cluster. This reinforces our opinion that is necessary to invest joint efforts to enable us to achieve greater and more diverse sample characterization.
- e) We have also noted that, in one institution, each one of the two students belonged, respectively, to the cluster with the highest and lowest satisfaction degree, information that came back to put in evidence the importance of knowing personal aspects relating to participants, so that we can characterize the causes for these differences in more detail.
- f) The groupware platform used by students to communicate during the semester seems to be perceived as a project weak point. The satisfaction degree with this variable is below the level of the expressed satisfaction with other aspects of the project.

Analysis of students' expectations

The subset of the questions asking students to rate their motivation degree and the degree of their satisfaction with the project (Table 9) were analyzed separately. The existence of four dimensions (Table 10) for which this happened simultaneously was verified. These dimensions are: academic, language, job and Europe.

Table 9
Motivation/Evaluation Questions

Motivations	Evaluation
2e1 - Motivations: Academic	5i - MUTW will help in further studies/career
2e2 - Motivations: Cultural	---
2e3 - Motivations: Practice of foreign language	5l - MUTW improved communication skills in an international setting
2e4 - Motivations: Friends living abroad	---
2e5 - Motivations: Career plans	5k - MUTW will help in finding a job
2e6 - Motivations: European experience	5n - MUTW improved European feeling
---	5m - MUTW improved team work skills
---	5j - MUTW helped improving creativity

Table 10
Dimensions for which Students Were Asked to Rate Both Their Motivation and Satisfaction Degree with the Project

Motivations	Evaluation	Dimensions
2e1 - Motivations: Academic	5i - MUTW will help in further studies/career	Academic
2e3 - Motivations: Practice of foreign language	5l - MUTW improved communication skills in an international setting	Language
2e5 - Motivations: Career plans	5k - MUTW will help in finding a job	Job
2e6 - Motivations: European experience	5n - MUTW improved European feeling	Europe

The comparison of students' responses for each dimension of analysis has created three levels expressing the strength of the motivation and satisfaction with participation in the project – mismatch, match, exceed. Mismatch means that the score given to the experience evaluation is worth less than the score given to the corresponding motivation; match means that the assigned values are equal; exceed occurs when the score given to motivation is lower than the score corresponding to the evaluation experience.

Table 11 allows the identification, for each one of the analysis dimensions, of the proportion of responses corresponding to different levels of expectation.

Table 11
Expectation Degree per Dimension

		Dimensions			
		Academic	Language	Job	Europe
Expectations	Mismatch	29%	18%	47%	18%
	Match	41%	41%	41%	53%
	Exceed	29%	41%	12%	29%

The data in Table 11 shows that the Job dimension has the highest mismatched expectations value. Europe dimension is the most common in the set of matched expectations. Concerning the exceeded expectations, there is evidence highlighting the language dimension.

Considering all the expectations dimensions (Academic, Language, Job, Europe), it is possible to obtain the global expectation, EG, which can be compared with the global evaluation, G. The intensity of the relationship between global expectation, EG, and global evaluation, G, was measured with the correlation coefficient Spearman's Rho (with the software SPSS 17.0). It was verified the existence of a very low linear association, with Spearman's Rho = 0,199, sig = 0,444, which is not statistically significant.

The lack of correlation may indicate:

- The four dimensions evaluated in global expectations fall short, thus not allowing the comparison to the global evaluation. Therefore, it is recommended to adjust the student feedback questionnaire so to have a complete correspondence between the motivations questions and evaluations questions of the project.
- Doing motivation evaluation at the same time as the project evaluation may bias the students' responses. Therefore, is recommended that the motivations be evaluate prior to the start of the project (pretest) and also at the end (posttest).

Content analysis of open questions

The analysis of qualitative data obtained from the open questions of the Student Feedback Form was completed using the content analysis, having been given the analysis of frequency as a criterion of objectivity and scientism.

Following the parameters used by Bardin (2004), content analysis behaved pre-analytical steps, scanning and processing and interpretation of responses to questions relating to the MUTW experience.

The pre-analytical observation of the rules meant to be exhaustive (selection of any material likely to be used), representativeness (the data were obtained through the same technique and performed with similar individuals), homogeneity (the withheld documents comply with specific criteria of choice) and relevance (the withheld documents were adequate to the purpose of analysis). In this first phase, after the organization of materials and systematization of the initial ideas, we performed a systematic reading of the open answers. In the exploration phase of the material, following the recommendations of Bardin [47] and Minayo [48], the raw data were processed to reach the core of understanding the text. We performed the classification and aggregation of the material responses. In this exploratory phase it was necessary to transform the raw data of the text to achieve a representation of its content. All responses to each open question were taken as context units. Each of the responses was the target of treatment and qualitative interpretation of its constituent parts, the units of analysis, resulting from the analysis of these units, the categorization. As a rule of enumeration, we have used frequency, represented by the number of times that a particular category appeared referenced in a response to the item under review. Systematization of the categories of analysis emerged from their respective themes or meaning units, found from the literature review that guided the preparation of this study.

The information collected in connection with the description of the aspects of MUTW that were perceived by participants in the project to be most useful for promoting their academic development has allowed the identification of five themes, which together add a total of eleven categories of analysis.

The analysis of these responses revealed the following themes: cooperative structure, identified in 83.2% of responses; nature of the tasks presented in 69.4% of responses; process of self help / personal development, identified in 84.3 % of units of analysis, interpersonal development, cited in 70.5% of the units of analysis and perception of high levels of equality and reciprocity, present in 32.7% of responses.

Under the theme cooperative structure, the responses were divided into three categories: cooperative learning itself (17.2% of respondents); explanation by peers (5.9% of responses) and collaboration among peers (60.1%). As examples of analysis units that allowed the identification of categories of cooperative structure theme we have found: "colleagues give individual contributions to the success of collective work," each one is helping isolated and there is no difference between the group members' and "colleagues with the same level of knowledge working together on tasks."

The subject nature of the tasks was established based on the categories: specialization of tasks (8.7% of responses) and group tasks (58.6% of responses). This theme includes responses such as: "meeting of routines written," every part of the protocol meets fellow, "" joint decision-making (...) thinking about ideas, ", " discussion and confrontation of perspectives, peer interaction in attempt to solve problems".

The theme of self-help process | development staff was composed by the resilience (24.2%) and feeling of enjoyment (74.2%) categories, categories that resulted from responses such

as "adaptation to new contexts"; " more capacity to accept change, " adapting to situations of competition between colleagues "; " correspondence between individual needs prior to group work and peer reinforcement and stimulation group", "confirmation of expectations pleasant experience".

The theme of interpersonal development includes conflict reduction in school (32.7%), and promoting social inclusion (42.3%) and was formed based on units of analysis as: "It helped to be more comfortable to know colleagues "" I'm more comfortable talking with people who previously did not know " and " I belong to different groups in different contexts and it is good to increase the number of friends".

The reference to the perception of high levels of equality and reciprocity (32.7%) includes the response category on the perception of competence between the group members (14.1%) and the category of responses equal status among group members (20.2%) and this theme include units of analysis such as: "Everyone contributes in equal measure to all of the tasks of work"; "All decision makers and opinion of everyone has the same weight than that of any colleagues "; " There's specialists and responsible work, and (...) all are important for the final result. " .

The information collected in connection with the description of recommendations and ideas for the MUTW organizers allowed the identification of a theme, promotion of soft skills, which adds a total of four categories of analysis: need for training in the skills of time management (39, 3%); proposal to increase opportunities for reflection, discussion and confrontation between the peer group (28.7%); perception of shortage of skills for managing conflict (21.7%) and increase opportunities for training of communication skills (10.9%).

CONCLUSIONS

The analysis of the data obtained through the student feedback form, allows us to conclude in general that the pattern of findings of MUTW evaluation is favourable.

Our hypothesis – MUTW contributes to improve students team work and communication skills at an international level – is statistically supported by students' answers. We may accept at a 5% significance level that MUTW improved team work skills due to the academic/learning outcomes of MUTW and also that MUTW improved communication skills in an international setting due to the innovative aspects in the project execution and the chance to profit from an intercultural exchange of experiences.

Taking into account empirical evidence from social cognitive theory of career and academic adjustment by Lent and colleagues (eg, [7,49,50]), we can affirm that such results reflect positive students emotional attitudes compared to academic life as well of self-efficacy beliefs and perceived availability of support and environment resources to pursue their personal goals.

Experience with MUTW is perceived by participants as being useful to support the role of cognitive and socio-environmental integration and adjustment to a career in higher education, which falls in line with Holland [51,52] and Lent [53], authors who guided the construction of the theoretical foundations of this project.

Concluding the assessment of the first edition of MUTW, maximizing the contributions of Shuell [54], and being aware that the fundamental task of teachers, especially higher education teachers, is getting the students to engage effectively in learning activities, we deem pertinent to stress that it is our conviction, after this year's work, that what the students perform is more important for determining what is learned than what the teacher does.

Therefore, and since in recent years, the authors of social cognitive theory of career have been explaining the influence of academic experiences and the peer group in various aspects of vocational development, it is important to emphasize that peer group in an academic context, is a source of relevant information in the process of constructing meaning around the assigned roles in modeling, evaluation, performance and merit, contributing to the development of higher education students vocational interests and values.

This analytical work, depending on its crosscutting nature, does not allow time to assess the prevalence of the analysis presented, which leads us to believe that this is a limitation of the assessment methodology implemented in this MUTW edition and suggests to conduct a longitudinal study, at the next edition of the project, that may enhance the examination of the temporal relationships between variables and the degree to which the predictors may be relevant to the change of criterion variables, as explained by social cognitive theory of career.

Given the incipient state of research-based test of an integrative model of well-being [53] and its application to specific career environments [55], theoretical model that guided the construction of this project, we think it will be useful in the future to examine the temporal relationship between variables in both samples of students who attend courses leading to different degree.

Since several of the relationships between variables that were tested in this MUTW edition are similar to those found in social cognitive theory of career [56], we deem relevant, that at the next edition of the project, we engage more explicitly evaluation of how the results boosted by participation in the MUTW project can be generalized to the labor field.

It also seems relevant at this stage of final evaluation of MUTW's first year to express our conviction that at project next edition, our concern should be to develop sample characterization, as exhaustive as possible. The sample characterization should include information regarding the route and level of academic success, and the existence of professional experience. The collection of social and academic information may increase our ability to identify the design features that benefit most the different groups of participants, and fostering the identification of projects strengths and weaknesses, that are experienced and valued differently by different groups of participants. This analytical work will suit the characteristics of the project groups, as we are better able to identify those who most benefit from it.

It also seems useful to consider the use of a quasi-experimental design, because such research will offer us a more rigorous testing of hypotheses. With this objective it is our conviction that we must consider the profitability of control groups in the next edition of MUTW. Using control groups may allow us to withdraw inferences that examine the temporal precedence or causality in the relationship between the specific variables under study.

Going according to the positions advocated by Crites [57] and Guichard [58,59], for whom the ideal context of the construction of representations of students' career in higher education is the shared meanings among the peer group, this international experience has enabled us to reflect on the importance of teamwork, as agents of socialization and "vocalization" of excellence for students in higher education.

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Mechanical Engineering Practice – using a simple Stirling engine as case

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ABSTRACT

The first technical course that students in mechanical engineering take at the Technical University of Denmark is called “Mechanical Engineering Practice”. We have used a simple Stirling engine as a design-implement project. Students were asked to design and build a heat engine using materials obtained by their own means and were competing on achieving the highest efficiency. We added an extra dimension to the project by making detailed measurements of the pressure variation to check simple thermodynamic models of the engine. The course had integrated lessons in sketching and technical drawing. The Stirling engine worked well in the drawing assignments. The Stirling engine also served as illustration of coming courses in mechanical engineering. The resulting engines had large variations in their design and most groups succeeded in building a functioning engine. However, achieved efficiencies were quite low.

KEYWORDS

Stirling engine, design-implement, design-build-test, first-year course.

INTRODUCTION

The Bachelor program in Production and Engineering Design (in Danish: Produktion og Konstruktion) is a three year program that represents classical mechanical engineering education at the Technical University of Denmark. Almost all students continue on a master program after completing their bachelor. The bachelor program is not designed as a CDIO education and therefore does not formally implement the CDIO syllabus. However, a few mandatory courses try to implement CDIO ideas. One example is the course in Mechanical Engineering Practice given on the first semester together with two general courses in mathematics and physics. The course in Mechanical Engineering Practice is the first course where the students meet topics specific to mechanical engineering.

It is common that introductory first-year courses include basic design-implement experiences [1]. These are sometimes called “design-build-test” projects. Popular topics are building model vehicles [2] or model aircrafts (“design-build-fly”) [1]. Other examples are building a Vertical Axis Wind Turbine [3] or a crane [4]. A comparison of many first-year design-implement projects was done by [5]. They found a high level of consistency across different institutions with most projects being done in small teams and with emphasis on practical sessions with a limited number of lectures and modest amount of faculty and money support.

It is common for design-implement projects to involve a competitive element to motivate the students. The competition should be on a parameter that is easy to determine like who travels the longest distance or achieves the largest power.

As discussed in [1], a design-implement project has multiple purposes. Besides being a motivating activity, it teaches students personal and interpersonal skills, strengthens the learning of material also presented otherwise and simulates professional engineering practice. Finally, for a first-year project, an important goal is to gain a deeper understanding of different engineering disciplines before selecting later courses to follow. At the Technical University of Denmark, students only have few mandatory courses and instead select courses in different categories. This makes it particularly important to give the students a background for making course selection later.

When selecting a problem for a design-implement project, there are several things to take into account. The course resources both in terms of cost of materials, laboratory space and faculty time per student are limited. The problem should have simple solutions so that all students have a good chance of creating one, but at the same time, the problem should offer plenty of challenge and enough complexity to simulate professional engineering practice. We suggest in this paper to use a simple Stirling engine as the problem.

COURSE OBJECTIVES AND CONTENT

The course in Mechanical Engineering Practice gives a credit of 10 ECTS point and is given during a 13 week period. The course is given for a full day every week. The afternoon is for most days used for lessons in sketching and technical drawing. In addition, the course has extraordinarily been assigned two hours an afternoon on a different weekday for extra lectures and presentations. The 10 ECTS point correspond to a total workload of 280 hours. This means that students are expected to work at home or in the workshop outside class hours.

Important objectives for the course are to:

- Introduce students to life as a university student
- Introduce students to core topics in mechanical engineering like solid/fluid mechanics, production technology, thermodynamics and materials with the main purpose of supporting selection of future courses.
- Give students an experience in developing a simple mathematical model of a product to analyse forces and thermodynamics.
- Let students practice construction and product analysis in groups.
- Give students some first experience in laboratory work, practical construction and measurements
- Teach three-dimensional sketching, technical drawing and Computer Aided Design (CAD).
- Let students document and present results in technical reports and through oral presentations.

As the course was given this time, about 40% of the course was given as regular lessons in sketching, technical drawing and CAD. About half of the course was a design-implement project that involved core topics of mechanical engineering as mentioned above. Teachers of coming courses in core topics in mechanical engineering were invited to give short presentations of their topic with examples applied on the design-implement project and followed by a question-and-answers session where students could get advice on their

project. The course had a few other elements like a talk by an experienced engineer, visits to two companies and presentations by older students advising on studying routines.

A new objective that we wanted to test in the course was to let students make measurements on their construction to test their mathematical model of the construction. Many of the first-year design-implement projects mentioned earlier basically only do measurements on the single parameter like travelled distance used in a competition. We wanted to make more detailed measurements to test details in the models. This is obviously more complicated, but it creates a much stronger link between theory and practice. It is possible to get simple and cheap measurement systems that can be handled and changed by the students. A typical solution is to use USB-based acquisition hardware together with the LabView software.

STIRLING ENGINE AS CASE

We have explored using a simple Stirling engine as a case for a first-year design-implement project. A Stirling engine is a heat engine that works on a gas in a closed system where the gas typically is moved between two cylinders with pistons. The most convenient design for a student project is the so-called “Gamma” configuration operating with air as medium. This design has a cylinder with a hot end heated by a flame and a cold end cooled by the surroundings. The air is moved by a piston (displacer piston) between the hot and cold ends. This changes the pressure in the closed system. A second cylinder is connected to the first cylinder. Here a piston (power piston) makes expansion and compression strokes extracting mechanical energy from the system.

A simple Stirling engine has a number of properties that make it well-suited for a design-implement project:

- A functional engine can be build using cheap materials and simple tools
- There is a huge solutions space both in terms of fundamental configurations and in selection of parameters and materials. This makes it a good simulation of professional engineering practice
- Most disciplines within mechanical engineering are involved in the design of a Stirling engine
- Students can make a mathematical model based only on geometry and the ideal gas law and get fair agreement with measurements
- The engine has a level of detail that makes it suitable as a final assignments for sketching and technical drawing
- It is very motivating for students (and for some surprising) that they can build something that moves by itself

The first challenge is to get an engine that runs at all. The most important factor is to make the engine reasonably airtight and at the same time have low friction for piston movement. This gives a basic insight in machine elements and manufacturing tolerances. Further optimization of the efficiency is typically related to selection of size of air volumes, pressure drop in channels and heat resistance in different places. Here simple models and estimates provide important help. When speed increases with optimization, component strength and machine dynamics becomes important. All these parameters link mechanical engineering disciplines to the project.

There is plenty of material on hobby Stirling engines on the internet. An example is a large amount of videos found when searching for “Stirling Engine” on youtube.com. These serve as inspiration for students when designing their own engine. Sorting out what is actually going on in videos or whether an explanation of a principle is plausible, is a good exercise in the process of doing one’s own design.

The students can manufacture most of the engines components themselves by simple means, but will discover that a few key components have higher requirements for tolerances and manufacturing technique. They therefore learn to appreciate help from professional technicians on these key components.

Finally, we were fortunate to have a start-up company on the university campus that manufacture biomass fuelled Stirling engines (Stirling DK, www.stirling.dk). A visit to this company and discussions with engineers from the company was a great motivation for the students.

COURSE STRUCTURE AND ASSIGNMENTS

We organized the course around a competition: “Make a machine than converts heat from a flame to mechanical energy on a shaft”. The main price was given to the engine that demonstrated the highest energy efficiency. Other prices were given for original design and best analysis/documentation. Finally, we had a fighter price for a group that tried an unconventional solution. The competition had a few extra restrictions: the cold end had to be cooled to the surrounding air; the engine had to be tested under steady conditions and no other consumables than the fuel for the flame could be used. This ruled out building a simple steam engine or cooling the engine with ice. The engine should be manufactured by components that the students obtained by their own means. However a few components could be manufactured by technicians in our workshop if the students provided a correct technical drawing. The students were divided into groups of 4 persons that worked together for all assignments in the course. About 65 students participated in the course.



Figure 1. Stirling engine built by students on first day of the course.

To get students convinced that they were able to build a Stirling engine, they were given parts and instructions to build a first engine on the first day of the course. The main components where a tin can, a balloon, a Compact Disc, a short plastic pipe and some pieces of wire, wood and plate – see figure 1. A brass fitting for guiding a wire holding the piston in the tin can was made in advance by the workshop and mounted on a circular plate. Some other pieces of plate were also cut and prepared. This was done to save time on the first day. The engine could run on a small candle. Figure 2 shows students building this engine. Nearly all groups got a running engine within a few hours of work.

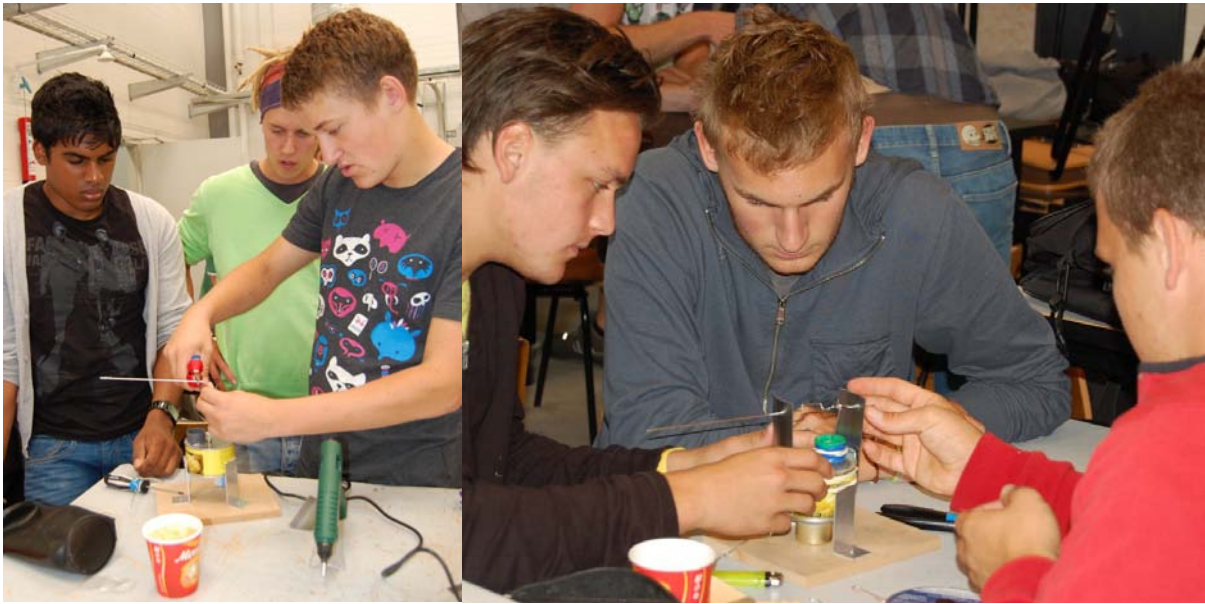


Figure 2. Two groups building a “tin can” engine on the first day of the course.

The second assignment was to model different aspect of a transparent Stirling engine. The engine was a commercial design for educational purposes (model GT03 from Stirlingshop.de), see figure 3. We instrumented this engine with a pressure measurement in the power piston cylinder, temperature measurements of hot and cold ends of the main cylinder and support for simple measurements of the shaft torque. Students were given a few lectures on modelling of forces, strength of a rod, how to model thermodynamics using the ideal gas law and how to estimate pressure drop in channels. Students were asked to make a short technical report showing model calculations and comparing to observations. The thermodynamic model gave an estimated power that was twice the observed power. Students were supposed to argue that the main reason for this difference was friction and pressure losses.



Figure 3. Transparent Stirling engine used for second assignment

The final assignment was to construct an engine for the competition. Students were offered a solution for a power piston with an acrylic cylinder and a brass piston with a standard diameter of 27 mm. The power piston is the most critical component with respect to low friction combined with almost airtight operation. More than half of the groups selected this option. The final construction was documented by the group in a technical report and was also presented in a poster presentation with running engines on the last day of the course.

Assignments related to lessons in sketching and technical drawing were given in parallel with the assignments on Stirling engines. Students were asked individually to hand in sketches of ideas for engines considered in their group. Each student was also asked to do a CAD model of the group's final construction. Finally, drawings used in the technical reports were also included in the student evaluation.

EVALUATION AND PLANNED IMPROVEMENTS

The course was in general very well received by the students. They spent many hours constructing their own design and the solutions had a large variation. Examples of solutions are illustrated in figure 4 and 5.



Figure 4. Two examples of successful engines. The engine to the right won the competition on best efficiency.

A few groups did not get their engine running. Some groups did get an engine running, but did not succeed in measuring the efficiency. About half the groups had an estimate of the efficiency and a few groups managed to get detailed measurements of pressure and temperature on their engine, see figure 6. The maximum efficiency (power on shaft divided with fuel consumption) where not impressive with the winning teams solution (see figure 4) having an efficiency of 0.06%.

Many elements of the course were developed on the fly, especially techniques for measurements. It was difficult to predict what kind of engines we could expect the students

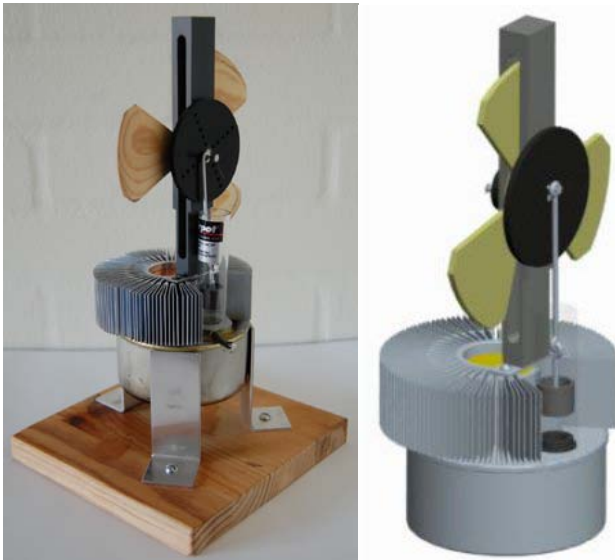


Figure 5. Example of successful engine (left) and the CAD model of the same engine (right).

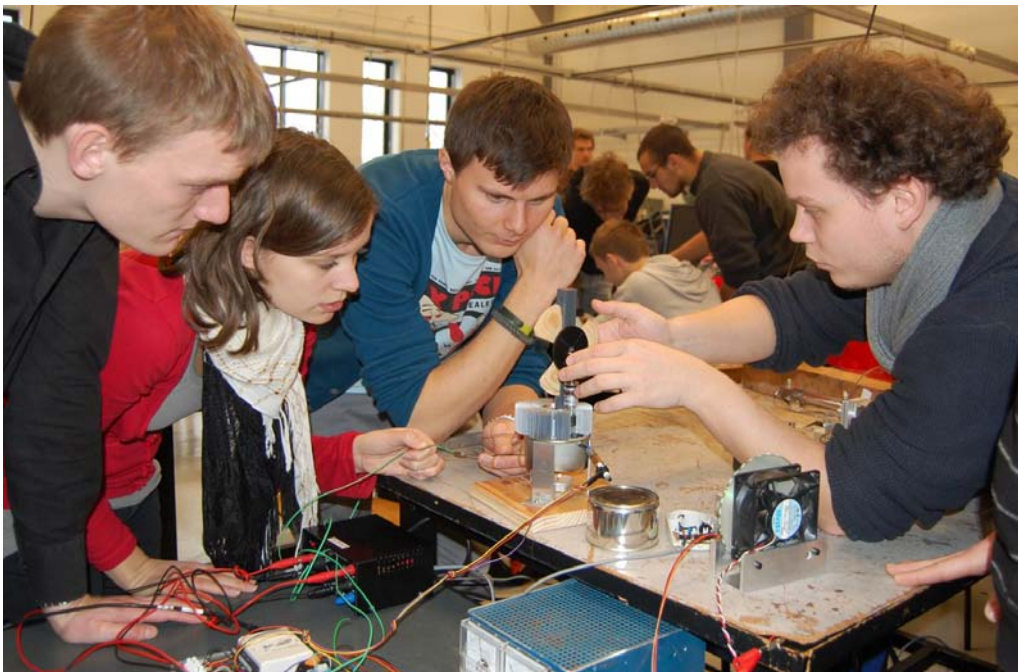


Figure 6. Group during measurements on their own design

to make and therefore also what measurements they could do. Next time, we will introduce measurements earlier in the course to make the students include support for measurements in their design from the beginning. We expect that measurements earlier in the design process will improve the design significantly.

Students were in general very motivated at lectures and were asking many questions. This probably reflects that they realised that topics were important for their project.

Student evaluation of the course was in general positive with 84% of the students in their evaluation of the course agreeing that the course was good or mostly good. We got positive comments like “very motivating to build your own engine”, “hands-on from day one”, “you get a good overview of the later [elective] courses” and “great fun to actually do something in practice”. Several critical comments related to issues around lessons in sketching and

technical drawing. This will be organised differently next time the course is given. Another issue raised by several students was the lack of a textbook and course notes. We intentionally handed out only brief material on the physical modelling, since it is a part of the assignment to develop the models from scratch. However, it is important to make this even clearer for the students. Finally, some students complained that lack of time prevented them for getting all things right. Since lack of time for understanding all details is a fact of life for most students, we will make this point even more clear in future versions of the course.

CONCLUSION

We consider the idea of using a simple Stirling engine in a first-year design-implement course a success. Compared to other published first-year design-implement projects like building a vehicle or a wind turbine, the Stirling engine involved more mechanical engineering disciplines, especially thermodynamics. We find it useful integrating detailed measurements to check simple models of the operation of the engine. Evaluations by students and teachers have been quite positive. We plan to use the simple Stirling engine for the first-year students in future courses and expect to improve implementation of the project based on our gained experience.

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COMPLEXITY IN DESIGN OF DIGITAL SYSTEMS: ACTIVE LEARNING WITH PUZZLES

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ABSTRACT

In engineering education, puzzle solving has long been used to develop critical thinking skills. We here put forward the use of Jigsaw Puzzles in a degree program of electrical engineering for two main purposes: (1) Introduce the concept of complex systems, and (2) Justify the need for a methodological approach in a course of Digital Systems Design. This activity was carried out during the first week of the program course and it has been designed to be conducted in three progressive stages as the level of difficulty in puzzle solving increases. As a preliminary result, we have recognized the high impact in developing communication and teamwork skills, and the need of taking a methodological approach to solve problems.

KEYWORDS

Puzzle-based learning, Complexity, Engineering Design Methodology, Digital Systems Design.

INTRODUCTION

In general terms, complexity is defined as the quality of an object with many interconnected attributes and elements, fact which, in turn, makes the relevant object one difficult to understand as a whole. Complexity has been an item of study and research in areas such as computing, biology, information theory, and engineering [1]. Complexity, as far as engineering is concerned, has been mainly studied in the context of systems design. Design, in turn, is considered engineering's most important activity [2]. Furthermore, recent initiatives in education, such as CDIO (Conceive-Design-Implement-Operate Initiative), lead by MIT in conjunction with Boeing aerospace company (initiative in which Universidad Javeriana's Electronic Engineering Program takes part). CDIO established that «design in engineering constitutes the essential context vis-à-vis the training of an engineer ». According to the Accreditation Board for Engineering and Technology (ABET), design in engineering is generally an iterative decision making process whose main purpose is to conceive systems, components, or processes to satisfy some of society's specific needs by resorting to natural sciences, mathematics, and the basics of engineering and thus optimize the transformation of resources to achieve specific objectives thus, a complex system is defined as one with a great number of not easily interconnected parts. In order to ponder any product's design simplicity or complexity, the represented number of functions must be considered, its functioning principles assessed, and its symmetry and topology (among other factors) examined [1].

For this paper, we stick to Marashi and Davis' definition, i.e. that complex systems are those which contain multiple components and layers of subsystems with multiple non linear interconnections difficult to recognize, manipulate, and/or predict [5]. As a way to approach

complexity in engineering, given the lack of scientific principles in the processes behind any design, Nam Pyu Suh has pioneered a method which he has called axiomatic design, in which he proposes a set of axioms and corollaries based on (1) maintaining the autonomy of the functional requirements, and (2) minimizing the information content of (or in) the relevant design. In following with his proposal, a good design would be one that satisfies all the functional requirements with the least number of components and relations [3].

Yet, in spite of the efforts to maintain a minimum number of components in a system, there are areas of electronics, such as digital design for example, where a steep increase in the integration of functions has meant that the number of components on an integrated circuit has doubled every two years as, by the way, was established by Moore's Law. By 2010, the trend implied by this Law will be five years old since it was first predicted in 1965 by Gordon Moore [8], one of the founding members of Intel. This increase in complexity, inherent to the number of components, leads to the necessary introduction in electronic engineering, more specifically in digital design, of working methodologies to better cope with the complexity of these systems and we think that this concept should be approached from the word go with undergraduate education. In this paper, we show how puzzles are used to explain the concept of complexity. The paper is organized as follows: In Section II, "The Need of a Methodological Approach to Cope with Complexity in Digital Design Systems", an attempt is made in order to explain why the high level of components integrated in the design and manufacture of integrated circuits demands the introduction of methodologies, in both industry and academia, to cope with such complexity. Then, in Section III, "Incorporating Puzzle Solving in Learning Processes", we describe the context and background of several years work in understanding learning processes done by the Research Group MIMESIS, whereby technologies were presented together with innovative classroom experiences. In Section IV, "The Puzzle Solving Experience", we describe real activities with puzzles, and in Section V, "Preliminary Results", presents the result of the activity realized in 2010. Finally, this paper offers, in Section VI, some Conclusions in the proposed didactics.

THE NEED FOR A METHODOLOGICAL APPROACH TO COPE WITH COMPLEXITY IN DIGITAL DESIGN SYSTEMS

Our age's continuous and growing technological needs have meant that electronic systems have become more and more complex and that a greater diversity and number of functions are integrated into them. This is particularly true for digital systems which grow almost on a daily basis, fact which explains why both academia and industry are permanently in search of new ways to better approach this challenge [11], [10]. In order to understand the levels of complexity nowadays in use, we must take a look at the historical evolution of digital systems.

The first integrated circuits, which appeared by the end of the 1950's, had a few a transistors, but today's processors, which we find in all personal computers, can have over 2000 million transistors [6], fact which, when in the midst of the process of design, can be difficult to handle without clear guidelines. However, there is no unique standard methodological approach to develop this type of systems; on the contrary, different manufacturers and academic institutions have offered different proposals in an attempt to be more efficient vis-à-vis their particular concerns. Yet, many of those methodological approaches have points in common [11], [9], [12], which we can sum up as follows: Generating multiple perspectives and levels of abstraction; segmenting the process, and acknowledging the need for multiple work teams. The levels of abstraction start with the functional requirements of the system to be developed which, once examined, allow for the creation of input-output diagrams that define the most important functions. The next stage is to define the actual architectural construction, whereby the whole system is gradually broken down into simpler blocks which in turn carry out more specific functions. This description is very important and is carried out by iteration and increment. The level of the gradual break down is permanently modified until

the designers consider that the system has been properly described, at least in as far as static notions are concerned. Next, the dynamic behaviour of the system is defined to produce its time and state diagrams and even an HDL (hardware description language) in order to describe the systems' dynamics. With these descriptions at hand it is now possible to proceed to its physical installation, a process which can be done by means of multiple computational tools which in turn open the possibility to analyze and examine the system's physical behaviour. New perspectives and levels of abstraction will now be obtained, i.e., layout and distribution at semiconductor levels. The latter levels are of crucial importance because they have a deep and direct impact on performance, that is, even if the newly conceived system can accomplish all the functions for which it was created, we must bear in mind that it must accomplish them in the required time without resorting to a larger power load than the one that was previously established and it should be small enough to fit in a final product which looks attractive to the customer. Thus, of course, if by the time the installation stage is over and the product does not fulfil the desired characteristics, it would be necessary to review all the previous stages in order to finally satisfy all the requirements demanded by the client/user.

All of the above explains the need to develop new design technologies in order to interact with the complex systems that in turn need to be created. These new methodologies involve teamwork and rigorous documentation in order to achieve the coordinated interaction of the hundreds or thousands of persons who work on one same system. It is thus urgent and pressing that today's engineering students understand this complexity and be able to come out with tools to overcome the challenge and join other consolidated work teams.

INCORPORATING PUZZLE SOLVING IN LEARNING PROCESSES

Puzzle solving, as well as other related projects, are embedded in a teaching-learning model proposed by the research group MIMESIS. The model has two basic premises: first, the students must play an active role in their learning process; and second, hands-on process of learning, using several easy available didactic materials and incorporating activities in the classroom in order to understand and apply the main concepts to be used during the course.

The model has been basically implemented in courses under the area of Digital Techniques, which makes part of the Electronic Engineering degree course at Pontificia Universidad Javeriana of Bogotá, Colombia. The latter is a five (5) year undergraduate degree course whereby the subject Digital Systems Design is compulsory and is offered on the fourth year of studies. In it, team work and collaborative learning are encouraged via practical exercises which, nevertheless, still foster the students' autonomous training. Logic Circuits are a prerequisite and is followed by Architecture and Organization of Processors, subject in which the students design their own processor. As far as we know, it is one of the few proposals in which undergraduate students are exposed to the task of designing their own processor, similar to those they use in their conventional PCs, but with tailor-made functions defined by the student him/her-self. The subjects studied over the last years under the general umbrella of Digital Techniques, have undergone several changes due to two main basic factors: the advances in technology and the changes in the teaching methods. To begin with, advances in technology allow electronic designers to develop and produce, at competitive prices, very complex digital systems that in fact do work in the real world and perform with the same ease that many other high capacity devices offered in the marketplace; on the other hand, the tools from manufacturers now available for designers, make the possibility of closing the complete cycle of design a feasible one, that is, carry out the whole process: conception, verification, implementation, validation of specifications, and the systems operation. All these procedures now come across the subjects' contents, including the methodologies necessary to support the mentioned design stages.

With this in mind, the relevant subject matters have changed in such a way that the students can build their knowledge and acquire the necessary skills to produce reliable and easy to

maintain designs, always bearing in mind limitations such as costs both in time and money. On the other hand, the methodology used in the classroom has also undergone huge modifications when late magisterial expositions are compared to today's actual learning based on PBL that foster collective and collaborative work. Thus, the lecturer takes on the role of a guide of sorts, and actually guides a process in course with very few instances of cheer magisterial exposition. The physical arrangement of the classroom itself has changed. In order for the groups to better carry out their work, the classroom's furnishings allocated to these courses is now modular and flexible, so that they can be adjusted and reconfigured depending on the activities to be performed in each class. During the Digital Design course, for example, it is important that students become aware of the fact that a complex system is usually not developed by a single person and that, as is true in most industries, a product of this nature is developed by work groups with different functions and, at times, even groups and peoples working in different parts of the world and where, needless to say, the process of communication is essential.

THE PUZZLE-SOLVING EXPERIENCE

The experience with puzzles is introduced as soon as the Digital Design course starts, that is, during the first week. The idea is to use the puzzles to explain and show the need of a clear methodology when designing, to highlight the importance of team work and effective communication, plus introducing the concept of complexity. From Marashi and Davis' proposed definition for the concept of complexity, we took two elements and applied them to the design of systems. The first alludes to the notion of complexity as the number of elements that comprise a system and the second to the level of difficulty with which the parts that make up a system interconnect with each other. We set up an experience whereby puzzles are used in three progressive stages through which the two proposed elements are incorporated into one complex system. An even number of teams, each comprised by 3 to 4 people, are constituted and their members assigned a role: each team will choose a person to measure time and take notes. The teams must have at least two members.

Stage 1

Introducing a simple problem; by simple problem we understand one with a limited number of pieces easy to interconnect with each other. We chose a 6 piece puzzle which, framed together, made up a big figure. Each team will be given a sealed envelope with a problem to be solved. None of the members knows the nature of the problem. Instructions are explained to all teams, and then, each team will open the envelope and find the problem to be solved as fast as possible. The problem to be solved consists in a flat puzzle of 6 pieces. Once the activity ends, time is registered and the person in charge of taking notes will share his or her annotations in order to examine the strategies adopted by the members and discuss them in a short plenary. The differences of time among the different will be discussed as well.

Stage 2

The complexity of the problem is increased by augmenting its connecting parts. The more variables you introduce to a problem, the more complex their work will be, thus the need for a methodology. Once again, each team will receive a second sealed envelope with a second puzzle. This time, contrary to stage 1, directions are different for every pair of teams and this time round all teams will solve the same puzzle. In short:

Direction 1: Solve the problem as you please.

Direction 2: Solve the problem with some guidelines to solve puzzles.

The new problem is a puzzle of 35 pieces. Once the activity ends, time is registered and the person who takes notes will share his or her notes. The adoption of new strategies will be discussed in a short plenary, contrasting their performance against the one proposed in stage 1. The differences of time will be discussed as well as the benefits (if any) of using and

sticking to a methodology. Once the discussion is over, students are asked to articulate a general methodology to solve problems such as those found in stages 1 and 2, methodology which will then be applied in the third stage.

Stage 3

This time round the complexity is increased by changing the rules that govern the interconnecting parts. The more difficult the interconnecting parts are, more complex their work will be, thus the need to adjust a particular methodology.

To finish the experience, each team will receive a third sealed envelope with no directions at all. It is assumed that each team will use the methodology proposed by the end of stage 2. The new puzzle will consist of 60 pieces, but contrary to the puzzles proposed in stages 1 and 2, this new puzzle won't be flat but spherical (without borders).

This new interconnection rule will imply a paradigm shift vis-à-vis solving puzzles that the participants will have to sort out. The later discussion will be focused on the relationships that now have been established between methodology and complexity, between styles of solving problems and reasoning as well as the steps followed by a particular methodology, plus the relationship between the concept of methodology itself and the need for adjusting it when faced with a new problem. Students are encouraged to apply an instrument for evaluation purposes.

After the experience with the puzzles, starting on the second week, a digital design methodology is introduced. Now the question of methodology is approached from the system's perspective whereby the following stages of the process of design are introduced: 1) Understanding the problem, where the student is asked to draft a general description of the problem to be solved. 2) Top-down decomposition. Once the system can be explained in terms of inputs and outputs, the problem is segmented in simpler parts, a process also known as interface specification. 3) Once these simpler blocks have been pinpointed and their inputs and outputs identified, their interfaces need to be described via diagrams of blocks, their connectivity and times. 4) Describing the system's functionality. The students are encouraged to use an intermediate description level language, somewhere between structural and behavioral descriptions, which in digital systems is known as AHPL (A Hardware Programming Language). 5) Integrating the parts verifying that the system works as required. 6) Description in VHDL plus the subsequent configuration of the FPGA device. The principles at the base of the proposed methodology and the strategies used by the students to solve their puzzles are related, so that to begin with, the problem to be solved is analyzed and broken down into simpler parts. Then the students deal with the problem of interconnecting the big pieces of the puzzle and the need to define as clearly as possible the relevant interfaces. Finally, they gradually learn how to integrate more complex problems. Along the course, at least three projects are presented to the students in order for them to implement the learned methodology when designing Digital Systems with different levels of complexity, that is, they will be exposed to systems with incremental levels of complexity in terms of the number of components which make them up as well as increments in the difficulty to integrate them.

PRELIMINARY RESULTS

As already said in the above section, the experience with the puzzles at the start of the course was divided in three stages, each one more complex than the one before. The puzzle's solution at the first stage is basically reached at intuitively and the time that the group takes to solve it depends on the particular skills of its members. Once this stage is over, an evaluation tool is implemented by each group in order to find the particular methodology used (even if unawares of such methodology) as well as the critical components which made the solution possible. Overall, collaboration among members and

drawing a plan to fulfil the task are always two very important elements for the design to succeed.

In the medium complexity stage, some groups work with a pre-established 'solution targeted' methodology while others work freely and follow no instructions at all. Overall, the shorter solution times come either from groups that follow a pre-established methodology or those that, before starting, establish their own particular strategy to solve the relevant task. Nevertheless, after carefully examining the work done by the different groups, we could see that for some of the puzzles the proposed methodology became in fact an obstacle which had to be modified and adapted in order to solve the group's particular problems.

When this moment arrives, it is time to ask all groups to put forward their own methodology and implement it for the final stage, whereby they will be given a spherical puzzle. At this level, the solution conditions change radically and the groups will have to adapt once more the methodology in accordance with the new context, point at which the methodological evolution should be not only obvious and necessary but iterative and incremental. As already said, the whole activity is attended with an assortment of tools to follow the connections that the participants make between the complexity of the device and the methodology used to solve the problem. Thus, to begin with, the students become aware of the importance of identifying the preliminary conditions and characteristics as soon as they start analyzing the problem, that is, at its first stage, step after which the problem can be broken down to simpler tasks with a sketch of fine granularity.

If we reflect on the aforementioned activity, we can identify five aspects which, in general terms, can be highlighted as critical elements relating the complexity of the problem and the methodology used to solve it: communication, teamwork, the ability to follow a methodical resolution strategy, the usefulness of a methodology, and the impact of all of the above on the process of reasoning. The first three befit the personal and interpersonal skills of an engineer; the last two are basically the students' perception of the skills themselves. Let's examine each aspect, one by one. The communication processes' main contribution to finding a proper solution is that it offers each member of the group the possibility to put forward his/her own ideas, learn from those of his/her peers, and thus put together the common task. In short, the students learn to listen, reach agreement, and evaluate. On the other hand, communication allows all members of the group to mediate among themselves, to keep track of the process' progress, put explicitly forward the norms and commitments assumed by the group, and work as simply and swiftly as possible.

In second place we have teamwork, an element which makes possible breaking down the problem into simpler tasks as well as encouraging a larger input of ideas for the benefit of the solution via the assignment of roles and responsibilities. Thus, a social configuration emerges whereby hierarchical structures are formed and leaders and followers identified. The groups' formation process is a natural one and they develop via the intercourse of feedback among peers and effective communication. The participants' teamwork efficiency will be manifest in things such as the time taken to solve the problem, the levels of harmony among members, the autonomous participation of each individual and their commitment to the group, all elements which contribute to a wider scope of learning than the one which would have been achieved individually. Students should become aware of the fact that teamwork adds to the strengths of all members and helps in overcoming each member's weaknesses. Still, in order to obtain the expected best results, they must also be aware that, to do so, processes such as planning the work ahead, coordinating the team vis-à-vis a clear shared objective, and each member's awareness of why, how and what he/she did are all essential.

The third aspect brought forward by the participants was that of setting out and then following a methodology, the latter working as a guiding sketch to get to solve the problem, but aware

of the fact that such sketch and methodology can be changed and modified in different contexts, that is, knowing that methodologies aren't unique and must therefore be flexible and dynamic; it is precisely these changes during the development of the problem, the element that alerts us to the need of methodological modifications and therefore becomes relevant when both identifying and understanding the problem and its particular characteristics. The methodological aspect is complemented by the fourth element, whereby the usefulness of the former comes to the fore. More complex problems demand more formal and rigorous solution methods, since a very simple methodology will be found lacking when dealing with a problem of greater difficulty. Posing an adequate methodology allows for solving the problem more efficiently, in less time, and thus makes optimal use of the available resources. Finally, the participants stressed that the activity they went through was like a simile of real life, whereby aspects such as communication, teamwork, and methodology are essential for a proper professional development as engineers, particularly when dealing with processes of reasoning and thought. The context of the experiment or activity, being as it is real, implies that the methodological processes used to solve such problem should not be mechanized, since each particular situation must be specifically analyzed and, furthermore, different solutions to the same problem must be confronted or pondered, meaning that each individual must be capable of evaluating and choosing the best possible option. Solving a particular problem offers knowledge that will be handy in future situations via the appropriation of clear methodological outlines which are flexible enough to be adapted the midst of particular future situations with new requirements.

CONCLUSIONS

Studies at University of Adelaide and Carnegie Mellon University have shown that there is a strong connection between the ability to solve puzzles and the ability to solve industry and business problems [4]. Puzzles are a fascinating way to learn problem-solving rules, among other things, because they are engaging and not directly related to textbook problems [7]. Puzzle-solving tasks develop skills needed in real engineering contexts and they reproduce effectively difficulties and conditions found in real workplace environments. The students agreed to the fact that the experience described in this paper did emphasize communication and teamwork skills although they were not mainly designed to develop these basic skills.

After the experience described in this paper is over, that is, once the students have solved the puzzles proposed and put into their own words their findings, it is easier for them to go into the concepts of complexity and methodology through papers and textbooks than it would have been without the previous experience. As far as the learning process is concerned, after years of research by the MIMESIS group, it has been found that giving more importance to the discovery of knowledge, from the students' perspective, can bring better results than using other approaches such as magisterial lectures from a professor's point of view. Jigsaw puzzle solving is a good metaphor for an engineering design process and the discovery of knowledge. It encourages inductive reasoning and fosters the ability to identify patterns in a large amount of data. This type of reasoning is essential for engineers and scientists. They are used here to introduce complexity and stress the need of using a methodology when solving problems. Furthermore, other topics related to the discovery of insight and knowledge and to engineering design can be explored to be used, for example, in the verification of processes in design, in following instructions, and in organizing and leading a group. We really think that such experiences can be replicated in the starting years of engineering programs to enable highly motivated students to succeed and to improve the students' continuity in the career in times when registration for engineering programs is declining. These activities can also be introduced also among school students interested in engineering programs, since they describe more effectively the type of work that engineers do on a real professional context. Quite often counsellors in high school scare students to panic because of the apparent difficulty in the study of mathematics and physics, leading to their choosing other disciplines.

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REFLECTION AND REFLEXIVITY IN REVIEWING AND EVALUATING CDIO: AN EMPIRICAL APPROACH TO EVALUATION.

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ADVANCED WORKSHOP

ABSTRACT

Facilitated by an Engineer and a Social Scientist, both of whom have expertise in Engineering Education Research and Evaluation (EERE), this interactive workshop is divided into three main sections, each one focusing on a different area of evaluation. It will build on research conducted at Aston University School of Engineering and Applied Science to explore and critique the value of introducing CDIO across the first year undergraduate curriculum. Participants will be invited to consider the pedagogical and engineering related challenges of evaluating the academic and practical value of CDIO as a strategy for learning and teaching in the discipline. An empirical approach to evaluation developed by the researchers to provide empirically grounded evidence of the pedagogical and vocational value of CDIO will form the theoretical and conceptual basis of the workshop. This approach is distinctive in that it encapsulates both engineering and social science methods of evaluation. It is also contemporaneous in nature, with the researchers acting as a 'fly on the wall' capturing data as the programme unfolds.

Through facilitated discussion and participation, the workshop will provide colleagues with the opportunity to develop a cross-disciplinary, empirically grounded research proposal specifically for the purposes of critically evaluating CDIO. It is anticipated that during the workshop, colleagues will work together in small groups. Suitable pedagogical approaches and tools will be suggested and a purposefully developed Engineering Education Research Guide, written by the workshop facilitators, will be given to all participants to inform and support the Workshop approach.

KEYWORDS: Evaluation, Evidence, CDIO, Engineering Education Research

BACKGROUND

The importance of Engineering in addressing some of Society's most pressing problems has recently come to the fore with issues such as the Japanese Earthquake and Tsunami, the Mexican Gulf Oil Spillage, the Icelandic Volcano and the continued problems caused by Global Warming making the headlines across the Globe. Furthermore, the need for the Engineering Profession to provide innovative and practical solutions to a range of high profile modern-day environmental, geographic, socio-political, economic and other problems is reflected in the academic, vocational and policy related literature [1] [2] [3]. Conversely, whilst much Engineering Practice may be conceptualised as being 'reactionary' in nature, proactive innovation and invention represent the most exciting aspect of the Profession. Manifested by practical and highly visible projects such as Large Hadron Collider [4], the Virgin Galactic spaceflight [5], and the Apple i-pad [6], such innovation and invention act to spark the public's imagination, bringing engineering and science to life in an applied yet accessible manner.

Given the complexity of contemporary Engineering-related challenges, the demand for Universities to provide a ready supply of suitably qualified Engineering graduates, equipped with high level employability skills, and are able to make innovative decisions and think 'outside of the box' is at unprecedented levels [7] [8]. Yet whilst innovation is often perceived to be one of the most exciting and crucial aspects of Engineering as a discipline, young peoples' misconceptions regarding exactly what the discipline constitutes represents a significant barrier both to Universities in attracting new applicants and to the Profession as a whole.

The situation is worsened by problems associated with high levels of attrition, with retention being a major issue in Engineering Education [9] [2] [10]. One of the main outcomes of this is that there is a severe shortage of young people entering the Profession at graduate level. Furthermore, whilst the current situation is undoubtedly troubling, unless urgent action is taken to remedy the situation, matters will deteriorate markedly over the next two decades. Indeed, in the UK, there is a likelihood that predicted shortfalls in the numbers of students expected to enrol on undergraduate engineering programmes over the next 10 to 20 years, will seriously test future governments' ability to retain and sustain local, national and global infrastructures and communities [2].

CDIO AS A SOLUTION

Questions of how to attract more young people onto University level Engineering Programmes are set within the context of high drop-out rates and failure – particularly in the first year of study. From a Higher Educational perspective, whilst many undergraduate Engineering Programmes have been transformed and updated to meet the changing needs of engineering students [11] [12], learning and teaching approaches to engineering remain a significant issue - with the subject generally perceived to be difficult and academically challenging. In addressing this issue, Aston University has introduced CDIO across its undergraduate curriculum for all first year students studying Mechanical Engineering and Design [13]. Introduced in October 2010, the new curriculum is intended to provide students with an exciting, practical, high quality and academically relevant learning experience. From its induction, Engineering Education researchers have 'shadowed' the staff responsible for

developing and introducing the new curriculum. It should be noted that emergent findings suggest that CDIO is generally perceived, by students and staff, to be a success.

EVALUATING CDIO: THE WORKSHOP APPROACH

Utilising an Action Research Design [13], and adopting qualitative research techniques, the researchers have worked closely with the teaching team to critically reflect upon the processes involved in introducing CDIO into the curriculum. Concurrently, research has been conducted to capture students' and lecturers perspectives of CDIO [14]. In evaluating the introduction of CDIO at Aston, the researchers have developed a distinctive research strategy with which future CDIO programmes may be evaluated. It is this research strategy that forms the basis of this interactive workshop.

By offering a series of interactive and facilitated activities, the workshop will provide participants with the opportunity to work through the epistemological, ontological and methodological steps taken by the research team in constructing a suitable research design with which to critically evaluate the CDIO programme.

The workshop will provide the opportunity for participants to begin developing their own approach to evaluating CDIO. It will commence with a group activity aimed at identifying and articulating the particular research related issues meriting evaluation within CDIO. By discussing underpinning theoretical and conceptual pedagogical epistemology and ontology the workshop participants will be encouraged to take a critical look at how they, and others, approach CDIO evaluation.

Having looked at the issues associated with identifying and refining suitable research questions, the 2nd part of the workshop will focus upon the selection of methodological tools and approaches. The strengths and weaknesses of different approaches will be briefly discussed and participants encouraged to reflect upon their own experiences in this area.

The final part of the workshop will bring the first two stages together allowing the participants to consider how they might approach future evaluation. The researchers will facilitate an exercise in which potential research areas and future collaborative partners will be identified and brought together.

Table 1, below gives a diagrammatic outline of the proposed schedule for the workshop. Participants are encouraged to sign up for the workshop in advance.

Table 1: Workshop Focus: Content & Context

Workshop Focus	Time schedule	Programme Content and Context
Introduction to workshop	5 Mins	
Theoretical and Conceptual Frameworks: Epistemology and Ontology	20 Mins	<ul style="list-style-type: none"> - Identifying research areas - Articulating research questions - Identifying suitable theoretical approaches - Developing theoretical frameworks - Identifying and critiquing conceptual and contextual variables - Refining research question
Selection of Tools: Quantitative, Qualitative or Mixed?	20 Mins	<ul style="list-style-type: none"> - Quantitative approaches in EERE - Qualitative approaches in EERE - Validation, reliability and transferability - Measurement and Evidence
Discussion and future collaboration	15 Mins	<ul style="list-style-type: none"> - Ideas for future evaluation of CDIO - Identifying suitable collaborative partners

BUILDING FUTURE PRACTICE

The workshop itself will be used as a research exercise. Following a phenomenographic approach the researchers will record the activities and interactions of the participants [15]. Participants will be asked, in advance, to sign a consent form in respect of their participation. All participant's individual and organisational details will remain fully confidential.

Following the workshop, the researchers will undertake a phenomenographic [15] analysis of the workshop findings. All of the data will be critiqued and used to further develop the original evaluative framework upon which this workshop is based. This will then be disseminated directly to the workshop participants. It will also be made available to the wider conference.

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ACTIVATING DEEP APPROACH TO LEARNING IN LARGE CLASSES THROUGH QUIZZES

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ABSTRACT

Large classes are challenging when designing learning activities suitable from a perspective of constructive alignment and at the same time being restricted to large class lectures due to external factors. In the present study a learning activity was desired to increase reflection and active repetition in a large class (75-100 students) of engineering students in a basic course in Materials Science and Engineering. Current repetition by lecturing was not satisfying from a learning perspective. Well known techniques such as mud cards and concept questions were not feasible, mainly for reasons of time to manage feedback or design proper concept questions. The aim of this paper is to describe a newly designed learning activity called Reflection quizzes, the process of design and also to analyse how student learning was affected. The result of the Reflection quizzes was overwhelming. The students were all actively engaged but took on different approaches; some discussed together (peer learning), some competed against each other (increasing motivation), some wanted to sit on their own using their notes (reflecting). The student survey showed that students appreciated to test themselves without it being assessed, many stated that the best was to find out why wrong was wrong and it was clear that they took on a more deep approach towards learning.

KEYWORDS

Large class, Active learning, Deep approach to learning

INTRODUCTION

Large classes are often a challenge. The course is ideally organised to attain “constructive alignment” as developed and described by Biggs [1], [2]. Learners are said to construct knowledge by their own activities, building on what they already know. Biggs claims that if learning is to take place, there should be clear intended learning outcomes (ILO:s) and the students should perceive these goals as meaningful. The assessment should be appropriate and there should be student-teacher atmosphere characterised by open dialogue. The design is then “aligned” if these clear ILO:s are supported by teaching and learning activities that make it possible for the students to acquire the knowledge and skills defined by the ILO:s and when the assessment appropriately test the fulfilment of the ILO:s. Moreover, e.g. Bloom has reported on the advantages for design of learning activities by applying taxonomy and stating clear goals focused on what the student should be able to perform [3]. It is also well known how important reflection is in order for students to take a deep approach to learning in e.g. a Kolbian coil manner as described by Cowan [4]. He suggests three planned reflections; *For*, to decide what the process will be to fulfil learning needs, *In* the middle to

consider how the process has fulfilled the aims and *On* the learning process to decide what has been accomplished and what is lacking; with the aim of improving.

However, in large classes traditional lectures are used even though they might not be the ideal learning activity for the intended outcomes. They are chosen for many other reasons such as time management, economy or tradition. In those cases it is important to attain as good result as possible by designing the lecture activities accordingly. Within the CDIO model for engineering education there are numerous good examples of course design that facilitates for students to focus on understanding. Many of the teaching strategies described are adapted for project based courses or smaller classes but there are also some applied in large classes [5]. Furthermore, in the literature there are described two well known strategies or learning activities to attain reflection and activity in the classroom; the use of mud cards [6] and concept questions [7].

Being a teacher with good experience of CDIO, I made some changes to a traditional basic compulsory Materials Science and Engineering course for 75-100 students trying to attain constructive alignment. The redesign included a change towards product focus (starting the course lecturing about a product instead of introducing the subject at the atomic level), elements of active learning during lectures, a writing assignment to apply theory to a real product, continuous assessment and a study visit. However, basic Materials for engineers is a subject that requires learning of many new words (e.g. martensite, bainite, hypoeutectic, peritectic and cross-linking) and it also brings about some new concepts that are complex to grasp such as phase transformations, dislocations, hardening or band diagrams. Both of these require that time is spent on repetition and reflection, and it was found important to design the lectures allowing time for this. 5-10 minutes in the beginning of each lecture was thus dedicated to repetition, but it was not satisfying. The perception was that it was boring for all including the teacher, and the efficiency of learning was low. Something else was needed.

The aim of this paper is to describe a new learning activity, called Reflection quizzes, that was designed to meet the need of repetition and reflection in large class lectures. The paper is organised as follows; firstly the process of design is described, followed by a description of the quizzes, a brief analysis on how student learning was affected and some concluding remarks.

PROCESS OF DESIGN OF THE REFLECTION QUIZZES

As mentioned, the course in Materials Science and Engineering required more teaching activities focused on reflection and repetition to facilitate for the students to attain the ILO:s as described in Table 1. The lecture started with revisiting the most important aspects of the previous lecture, but the choice of one-way communication was definitely not ideal.

“Mud cards” were tested, where students write a short sentence describing the muddiest point in the lecture on a card in the end of lecture. The students appreciated to write them and it led to active reflection. However, they raised an immediate urge for feedback which added too much administrative work on gathering and sorting and answering for 100 students attending 3 lectures per week. Frankly, it was the students that needed to spend more time on task, not the teacher.

“Concept questions” as described by Mazur [7] is a very interesting teaching strategy that definitely could be applicable in this case. There are numerous examples described by Mazur in the field of physics. But the design of concept questions in materials science was found to be quite a complex task. It should be the right questions, with three answers whereof one showed the right concept while the others catch common misconceptions. This resulted in a barrier. Moreover, the effect of concept questions is that the students invest in

their answering which generally is a very positive aspect of the learning activity. This could actually be a problem; I instinctively felt it might lead to a drawback for students with low self-efficacy. If repeatedly failed, it might become a high stake activity for them.

Table 1
Intended learning outcomes for the course in basic Materials Science and Engineering
(translated from Swedish)

After the course the student should be able to;	Comment
<ul style="list-style-type: none"> Describe how different types of materials (metals, polymers and ceramics) are structurally build up in terms of atomic bonding and crystal structure and discuss how the structure affects some of their properties. 	<i>Requires some rote learning of structures which requires <u>repetition</u>. The subsequent analysis of the relation between structure and properties requires <u>reflection</u> to be able to understand fully.</i>
<ul style="list-style-type: none"> Describe how, primarily mechanical, properties for the materials above can be affected by changes in the microstructure and be able to relate this to relevant hardening mechanism. 	
<ul style="list-style-type: none"> Use a phase diagram and a TTT-diagram; read it and from the diagram predict microstructure at a given heat treatment or cooling procedure. 	<i>Requires reading complex phase diagram and the same time imagine the solid state diffusion that takes place. Requires <u>reflection</u> on several levels to learn. Learning is supported by interactive software.</i>
<ul style="list-style-type: none"> Do a <u>simple</u> choice of manufacturing technique and /or heat treatment to attain specific properties and microstructure and discuss the choice of criteria to attain a desired result. 	<i>This is a difficult learning outcome which requires synthesis of the above outcomes. It is a pre-stage to the advanced master courses.</i>
<ul style="list-style-type: none"> Describe how corrosion is developed related to material and environment and discuss how to best avoid corrosion in a product. 	<i>Learning is supported by discussion in class on actual corrosion cases found by the students at campus</i>
<ul style="list-style-type: none"> Identify some selected polymeric materials 	<i>Learning is supported by experimental class</i>
<ul style="list-style-type: none"> Make a simple reflection on the material selection for an industrial product applying sustainability aspects. 	<i>Learning is supported by an interactive lecture of a workshop type</i>
<ul style="list-style-type: none"> Recognize product related problems which requires that the engineer needs to consider the microstructure of the material 	<i>Learning is supported by discussion two by two in class on several occasions</i>

In the end I just set up a list of wishes or demands of the desired learning activity which were: Student active learning, prompt feedback, reflection, if possible peer learning and not taking additional teacher time. Based on the demands I spent time thinking on how we learn completely different things today, using new technology. For instance it is very popular today among our students with quizzes on Facebook and other communities or a for instance a pub quiz. A quiz could accommodate all the demands and by making it less serious it could become a low stake activity; active but not far from the comfort zone.

DESCRIPTION OF THE REFLECTION QUIZZES

The Reflection quizzes are given during 5 minutes in the beginning of each lecture allowing the students to test themselves on how much they remember from the previous lecture. They are not expected to prepare. They contain 4-6 questions with multiple answers, as shown in table 2, and everything is allowed, with or without book, alone or together. Afterwards I go

through the answers briefly during 5 minutes, mentioning why the wrong ones are wrong, which supplies immediate formative feedback. If anyone wants to repeat further they can find the questions on the homepage afterwards.

Table 2
Sample reflection quiz

	1	X	2
Small grain size results in hardening 1. because grain boundaries stop dislocation movement. Small grains = large grain boundary area X. since dislocation movement is only possible if the grain is larger than 50 μm 2. but decreases ductility considerably			
Solution hardening 1. demands addition of atoms of a radius larger than the host atom X. harden since the presence of solute atoms creates a stress field, which dislocations have difficulty to pass 2. is only possible in aluminium			
Precipitation hardening 1. works out since it is possible to cut through coherent precipitates X. results in more hardening the more the particles grow 2. results in more hardening the closer the particles are to another			
Annealing 1. of cold rolled sheet is made in order to harden it further X. is done in order to heal the cracks that are developed during rolling 2. can result in three changes in microstructure (depending on time and temperature); recovery, recrystallization and grain growth			
Phase diagrams are 1. describing which phases that are present at a certain temperature and composition assuming thermodynamic equilibrium X. always determined experimentally 2. used to predict mechanical properties of different phases			

LEARNING DURING THE REFLECTION QUIZZES

The result of the Reflection quizzes was overwhelming. There is no claim that the questions are the right questions that assess how they will be managing the exam, just some fun tests on how much they remember from last lecture. This made the quiz easy to design, and accidentally some of the questions turned up to be quite good concept questions. It took in general 20 minutes to design a quiz.

The students took on different approaches; some discussed together (peer learning), some competed against each other (increasing motivation), some wanted to sit on their own using their notes (reflecting). All were actively engaged but in their own preferred way. Figure 1 below show how they are actively engaged in the morning, some use their books, some use their hands to explain to friends and some just make it as a test to see how they are doing.



Figure 1. Students engaged in reflection quizzes early in the morning

The comments in the student survey showed that students highly appreciated the possibility to test themselves without it being assessed, many stated that the best was to find out why wrong was wrong and it was clear that they took on a more deep approach towards learning. They stated that the course was mainly focused on student understanding instead of learning by heart. The quizzes were the most popular activity.

CONCLUDING REMARKS

In the present study a newly designed learning activity is described, called Reflection quizzes. It is intended to increase reflection and active repetition in a large class (75-100 students) of engineering students in a basic course in Materials Science and Engineering.

The result of the Reflection quizzes was positive. The students were all actively engaged but took on different approaches; some discussed together (peer learning), some competed against each other (increasing motivation), some wanted to sit on their own using their notes (reflecting).

The student survey showed that students appreciated to test themselves without it being assessed, many stated that the best was to find out why wrong was wrong and it was clear that they took on a more deep approach towards learning.

ACKNOWLEDGEMENTS

All my students the last years are greatly acknowledged for taking part in the development of different, more or less well functioning, learning activities without complaints.

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LEARNING AIRCRAFT DESIGN AND FLIGHT CONTROL SYSTEM DESIGN USING FLIGHT SIMULATION AS A CDIO CONDUIT

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ABSTRACT

Flight stability and control system design are problematic areas for teaching and learning in most tertiary institutions because of limitations in implementation and operation opportunities. Implementation and operation is a critical element of student learning because of the need for students to understand the relationship between design procedures and decisions, and their consequences in flight operation. Motion based flight simulation is a very effective mechanism for students to experience the transient responses and stability of a flight control system in flight, and to relate these back to the design process to reinforce learning. This paper describes how a motion based flight simulation facility has been integrated into a flight control system design course in a way that makes use of the CDIO principles. Students conceive and design a flight control solution for a given aeroplane, and then are able to embed that solution in the simulator and to operate the autopilot so as to experience the dynamics of their solution through the subsequent vestibular and visual stimuli. The paper also addresses how this concept is being expanded into a more thorough implementation in which courses in aircraft design, flight mechanics, and aerodynamics are being unified in a CDIO structure, with flight simulation providing capstone learning opportunities.

KEYWORDS

Flight Simulation, Experiential Learning, Control System Design, Autopilot, Aircraft Design.

INTRODUCTION

The training of student engineers was historically very practically based and trainers were typically industrial practitioners. In more recent decades this profile has changed somewhat with trainers in academic institutions becoming more research based. Training of undergraduate engineers has become far more theoretically based with less focus on practical training elements. There is recognition that the preparation of student engineers for industrial postings needs to be more problem based and experientially orientated. In fact a common complaint from employers of control engineers is that students need more laboratory and hands-on experience. Kheir, Astrom et. al. [1] outline the importance of practical experience in learning control systems engineering. They primarily address control engineering in mechatronics, manufacturing, process and electrical engineering applications, though the issues are generic to all disciplines. They particularly stress the pedagogical

benefits of experimentation, logic and sequencing training, CAD and the use of simulation as a means of making experimentation more accessible and affordable. Experiential learning through simulated practical exercises appears to be a key element in future engineering education.

In aeronautics in particular, there is a critical teaching gap between theory and practice as many of the concepts taught that relate to the operational significance of design, dynamics and control considerations are difficult to demonstrate to students due to limited access to flight demonstration capability. This is particularly true of smaller aeronautics departments that don't have ready and direct access to a fleet of different aircraft and flight test facilities. For small departments the limitations are imposed by the enormous cost of operating such facilities. In order to address these limitations, a number of institutions have been developing flight simulation capabilities as a cost effective and flexible means of providing virtual practical facilities to enhance engineering training. This sort of facility lends itself to implementation of teaching and learning initiatives that facilitate not only design exercises, but permit the once elusive implementation and operation stages to be integrated into the learning process. They therefore fit nicely into the CDIO teaching strategy.

The CDIO philosophy has instigated a resurgence in practical learning in the engineering academic arena. Its focus on the design process, taking a concept from inception through design all the way to the implementation and operation stages, is an excellent way of fusing the development of generic and discipline specific skills with learning of the operational significance of design decisions and considerations required to make the concept work. The realisation of a working system has a far greater impact on a student's motivation and learning than the disconnected theoretically orientated study of separate disciplines in isolation.

MOTION BASED FLIGHT SIMULATION IN ENGINEERING TRAINING

Historically, flight simulation commenced as a means for pilot training. It is only recently that they have been used for engineering training in an academic environment. Many of these developments address the teaching of handling qualities [2,3,4]. Some have been developed to address the teaching of flight control systems [5,6,7], though most do not involve motion and thus miss out on the important element of vestibular feedback. It is important to note that in these initiatives, the focus is on the learning of engineering concepts and how they relate to flight operations, and not on pilot training.

At the University of Sydney, the School of Aerospace, Mechanical and Mechatronic Engineering provide students with a number of hours of basic pilot training as a separate supplement to their studies. The purpose is to familiarise them with the skills, operational requirements and pressures of flying and aircraft. Simulation exercises are intended to then focus on the importance of the engineering training with this basic flying experience providing a fundamental contextual reference. The first implementation involved experiential learning of aircraft handling qualities by Variable stability Flight Simulation [8]. This initiative was introduced as an experiential learning to supplement to a 3rd year Unit of Study (UoS) called AERO3560 Flight Mechanics 1, in which students undertake thorough learning of flight stability, manoeuvrability and handling qualities. This simulation exercise is used to build upon their flight experience in a single very stable light aircraft by demonstrating the changes in stability and handling qualities that are associated with variations in key aerodynamic (design) parameters (something they cannot observe in a real aircraft). It also allows quick and economically efficient demonstration of the differences in handling qualities exhibited by a range of aircraft types (e.g. light aircraft, transport, training aircraft, fighter etc). The Variable Stability Flight Simulator is depicted in Figure 1 and Figure 2.



Figure 1: Variable Stability Flight Simulator



Figure 2: VSFS Cockpit Learning Environment

A subsequent flight simulation implementation has been introduced into a follow-up UoS AERO4560 Flight Mechanics 2, for experiential learning of flight control system design [9]. This implementation, being in a design based course, is a CDIO based strategy. It is the subject of this paper and is described in the next section. Both of these implementations have been assessed by before and after survey methods for their effectiveness in aiding learning of the key engineering concepts at hand. In each case it has been found that instantaneous knowledge improvements of between 12 and 20% have been achieved via the simulation exercises [8,9].

These achievements motivated a more broadly based CDIO integration into coursework where aircraft configuration design units of study are tightly coupled with units on flight mechanics and component design. In this framework the same flight simulation exercises take on more important learning consequences as they are then providing students with first-hand experience of how their own design products and procedures stand up to requirements, and are a strong provider of experiential and reflective learning experiences. The expansion of the 3rd and 4th year Aeronautical Engineering curriculum to a fully CDIO based structure is also described in this paper. This new structure incorporates links and interactions between students in various 3rd year UoS with the 4th year students in a capstone course involving aircraft configuration design. The Flight Mechanics UoS and flight simulation laboratories are keystone experiential exercises fully integrated into this strategy.

FLIGHT CONTROL SYSTEM DESIGN – CDIO IN A SINGLE UNIT OF STUDY

Outline

The course AERO4560 Flight Mechanics 2 is a final (4th) year unit of study in Aerospace Engineering and builds upon previously developed skills in flight stability and handling qualities developed in the core 3rd year course AERO3560 Flight Mechanics 1 [8]. AERO4560 treats the aircraft as a system and deals with a systematic analytical and design treatment for flight automation. Students study synergies between time and frequency domain representations of the aircraft's dynamics and study the response of an aircraft to control inputs, the response of the aircraft to stochastic inputs (wind gusts), and develop flight control systems to manage the flight path and to reject the effects of wind gusts on the aircraft's flight. The final component of the course is a major project involving the design, implementation and evaluation of stability augmentation and autopilot control systems. The flight simulator laboratory is then used to demonstrate the effects of well-designed, badly-designed and (if available), the student's own design of control solutions. As part of the

simulation exercise, the students are guided through a structured sequence of test points in which they fly the aircraft and engage the various controllers through the same control interfaces used by pilots. In this way they experience the transient performance characteristics of the closed-loop aircraft response to control system actuation and can connect these characteristics with their observations of their own controller performance from their analysis and design stages. This exercise has the secondary benefit of familiarising engineering students with the avionics equipment and processes used by operational pilots, thus they learn by first-hand experience the roles and functionality of the various cockpit instruments and avionics systems.

A typical major project statement involves the development of longitudinal control systems for the management of the dynamics and flight path in the vertical plane of a turboprop training aircraft. This aircraft model is chosen due to its agility, thus making the dynamics of the aircraft and control systems very observable for students. The goal is to modify the natural pitch characteristics and to control the vertical speed (climb rate) and altitude behaviour of the aircraft with a vertical speed autopilot, and to manage the airspeed with an auto-throttle. This is a multi-loop, MIMO (multi-input-multi-output) system (2 inputs and 2 outputs) with high order dynamics and non-minimum phase behaviour, and challenges students with very real analytical considerations and design decisions. The students design control loops and then analyse the performance of the controllers and the effects of wind gusts using CAD tools (MATLAB). Every second year the control task is alternated with an equivalent lateral-directional problem involving control of the aircraft in the roll and yaw axes using loops to control the bank angle and heading via the roll axis, while implementing a yaw damper to regulate the aircraft's behaviour about the yaw axis. For the purposes of illustration, the longitudinal problem is discussed in this paper.

The experiential learning exercise involves a session in the flight simulator in which students fly the aircraft and engage the autopilot and auto-throttle in order to study the transient behaviour and hence stability of the control solutions obtained. Two standard control solutions are provided, one 'good' controller and one 'bad' controller. These are used to highlight the ramifications of good and bad control design practice on the stability of the closed-loop aircraft behaviour. They are provided with design information that students can use to connect the flight results with particular features or flaws in design practice. If students have their own solutions available, they can be embedded in the simulator and flown so that students can reflect upon their design process after observation of the flight results (relative to the behaviour of the good and bad solutions).

Learning Components

The course develops the required system theory, analysis techniques and design tools and implements a hands-on methodology to learning.

Table 1 details the core study elements of four assessable computationally based assignments. The first three progressively develop the analytical techniques and skills required to establish a foundation for the control design exercise addressed in the major design project. The table also indicates the relationship of each of these with the core CDIO attributes. The major design project builds upon the collective skills learned and aims to take students through a realistic scenario of system design representative of that which might be experienced in an aerospace system integration company or flight simulator development organisation. In this project the students conceive and design a multi-loop MIMO frequency domain stability augmentation and autopilot system consistent with typical industry solutions. They then consider implementation issues and embed their control solution in the VSFS and will operate their system solution (and others) as a pilot would. The experience can then be used to reflect upon their design decisions, process and analysis for consideration of how the system could be improved.

Table 1
Flight control design UoS: learning components and CDIO attributes

Learning activity	Topics	Objectives	CDIO attributes (see Table 1 in [10])
Assignment 1	Linear system representation, transfer function representation	To develop numerical approaches to linear representation of aircraft response to control inputs via transfer functions (TF's). To develop an understanding of the aircraft's response via the TF only.	2.1 Engineering reasoning and problem solving - 2.1.1 Problem identification and formulation, 2.1.2 Modeling
Assignment 2	Time domain-frequency domain equivalence, time domain response of TF's to specific control input forms, frequency response functions	To develop an understanding of the nature of the time domain response of an aircraft represented by a TF. Develop an in-depth understanding of the links between time and frequency domain representations. Bode plot representation of aircraft frequency response.	2.1 Engineering reasoning and problem solving - 2.1.1 Problem identification and formulation, 2.1.2 Modeling
Assignment 3	Aircraft response to stochastic inputs (wind gusts). Gust power spectral representations.	To develop an understanding of the stochastic nature of wind gusts and their representation via power spectral density (PSD). To develop an understanding of aircraft response to gust inputs. To use analytical statistical tools and representations to quantify an aircraft's response to typical gust sequences.	2.1 Engineering reasoning and problem solving - 2.1.2 Modeling, 2.1.3 Estimation and qualitative analysis, 2.1.4 Analysis with uncertainty
Major Design Project	Classical flight control system architectures. Loop analysis and closed loop stability evaluation. Development of multi-loop multi-input-multi-output (MIMO) autopilot system.	To use analytical and control design tools to design compensators for stability augmentation and autopilot functions. Analysis of closed-loop stability of autopilot designs and assessment of closed-loop sensitivity to wind gusts.	2.3 System thinking - 2.3.2 Emergence and interactions in systems, 2.3.4 Tradeoffs, judgement and balance of resolution 2.5 Professional skills and attitudes - 2.5.2 Professional Behaviour 3.1 Teamwork - 3.1.1 Forming effective teams, 3.1.2 Team operation, 3.1.4 Leadership 4.3 Conceiving and engineering systems - 4.3.2 Defining function, concept and architecture, 4.3.3 System modeling and meeting goals 4.4 Designing - 4.4.2 The design process, phasing and approaches, 4.4.3 Utilisation of knowledge in design, 4.4.4 Disciplinary design, 4.4.6 Multi-objective design
Simulation Laboratory	Operational characteristics of control system dynamic response and stability. Assessment of closed-loop transient response and sensitivity to gusts inputs.	Students operate the cockpit autopilot interface (Mode Control Panel (MCP)) and test the transient response of closed-loop system to autopilot tracking commands. They also assess closed-loop sensitivity to gusts. Students assess a well-designed control solution against a poor design and their own design.	4.5 Implementing – 4.5.1 Designing the implementation process, 4.5.3 Software implementation process, 4.5.5 Test, verification and validation 4.6 Operating – 4.6.2 Training and operations, 4.6.4 System improvement and evolution

Conceive

Students are confronted with a system in which there are two primary control loops with cross-coupling influences and gust disturbance inputs. A typical configuration is shown in Figure 3, (where u and V_s are the airspeed and climb rate, and δ_t and δ_e are the throttle setting and elevator displacement respectively). The students need to decide upon a loop structure and establish the dynamics system representations involved. They must establish the closed loop relationships and the stability and performance characteristics implied. They also need to conceive the most appropriate form for each of the control compensators in the system. The design stage then involves selection of the quantitative characteristics of these components.

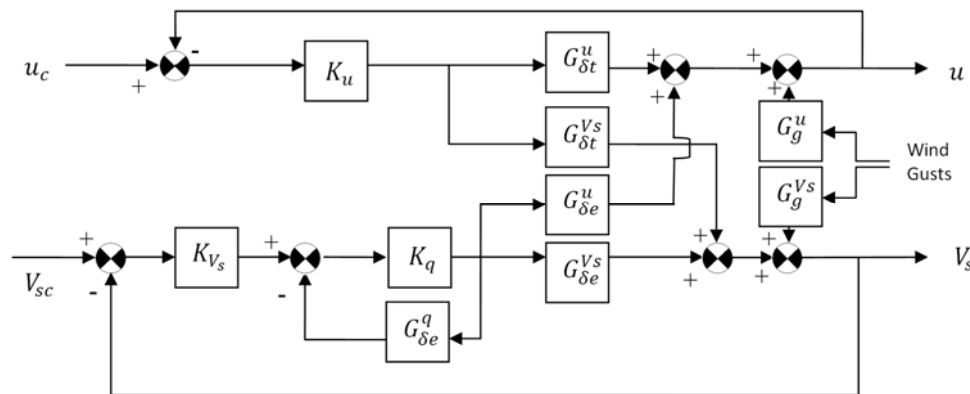


Figure 3: Typical system diagram

Design

Students use the Matlab Control Systems toolbox elements and apply Bode and root-locus design techniques to arrive at compensator design solutions to the problem given. They are expected to meet specifications regarding the transient performance, stability and steady-state tracking performance required. The control solutions are also required to meet certain specifications with regard to gust rejection properties using statistical analysis tools. These requirements are often conflicting and lead to design tradeoffs requiring the application of engineering judgement and intuition. Once their solutions are finalised, students implement them into their analytical nonlinear flight simulation scripts used for the design. This is a process of validation and verification to check that their controllers perform as predicted by the design tools and are robust to off-design conditions and gust disturbances.

Implement

Students study issues of real-time implementation of control system. These include sensing issues of noise and signal conditioning, the implications of discrete time-step on closed loop stability, and time domain implementation of frequency domain compensator designs. Students are given the real-time simulation parameters for the simulator to test with their solutions prior to implementation. They present their solutions in a prescribed format to comply with requirements of the simulator software system. Given that their control solutions are to be embedded in a flight simulator and will be driving a hydraulically actuated motion base, there are issues of occupational health and safety to consider. Each solution is therefore thoroughly checked off-line in an independent simulation environment by staff for stability and performance prior to implementation in the flight simulator so as to verify its safe operation. It is also tested in the simulator with the motion base disabled prior to operation

with motion. Once these tests are passed the solutions are integrated into the simulator and made available for operation in the demonstration sessions.

Operate

The simulation session procedure is outlined in a guideline document provided to students in advance so they can familiarise themselves with the procedure as well as the equipment. The session involves a number of scenarios involving the independent operations of the vertical speed autopilot and the auto-throttle, as well as their operation in conjunction. Table 2 details these scenarios and their purposes. The session involves running through this sequence of scenarios four times:

1. At the design condition 150Kn at 500ft, with well-designed controllers,
2. At the design condition 150Kn at 500ft, with badly-designed controllers,
3. At the off-design condition 90Kn at 500ft, with well-designed controllers,
4. At the off-design condition 90Kn at 500ft, badly-designed controllers.

giving a total of 24 test points.

Note: Test point pairs 1 and 2, or 3 and 4 will be replaced with student's control solution if it is available in the interests of maintaining schedule. The choice is dependent upon a pre-evaluation of stability and effectiveness of the student's solution as to whether it better demonstrates the characteristics of the standard 'good' or 'bad' control solution.

Table 2
Flight Simulation Scenarios

Test Point	Scenario	Purpose
1	Open Loop.	To establish a steady flight condition and a feel for the aircraft's response to the pilot.
2	Vertical Speed mode and Auto-throttle engagement – steady state.	To establish nominal autopilot performance and to hold a steady flight condition.
3	Vertical Speed mode engagement, climb at 1000 ft/min (without Auto-throttle) – no airspeed management.	To observe the transient performance of the vertical speed autopilot. To observe cross-coupling with the airspeed response. Airspeed will not be maintained.
4	Vertical Speed mode engagement with Auto-throttle, climb at 1000 ft/min – constant airspeed climb.	To observe the transient performance of the vertical speed autopilot and auto-throttle. To observe cross-coupling with the airspeed response. Airspeed will be maintained at nominal airspeed after transient response settles.
5	Vertical Speed mode engagement (0 ft/min) with Auto-throttle – level flight acceleration, increase airspeed by 30Kn.	To observe that with the vertical speed autopilot engaged, the airspeed is managed with auto-throttle. Observe performance of the vertical speed autopilot in maintaining level flight as airspeed changes. Observe airspeed transient response. Observe cross-coupling.
6	Auto-throttle engagement (without Vertical Speed autopilot)– level flight acceleration, increase airspeed by 30Kn.	To observe that with no vertical speed autopilot engaged, the auto-throttle will not manage airspeed due to the aircraft's natural flight stability.

The standard control solutions are designed specifically for the dynamics that the aircraft exhibits at a given flight condition – in this case 150Kn airspeed at 500 ft altitude. One of the major issues with control design is the robustness of controllers to variations in the operating point. Thus the performance of each of the controllers is demonstrated at an off-design condition (in this case 90Kn airspeed at the same altitude) to highlight the robustness (or lack thereof) of the design solutions. This is observed by the student through the inadequacy of the transient behaviour of the controllers, via sensory feedback.

For each scenario, students are given instructions in a guideline document on how to operate the equipment (also delivered verbally by the instructor during the sessions). An example sequence is given in Table 3 for Scenario 4. The instructions pertain to the operation of the control system through the Autopilot Mode Control Panel (MCP) interface shown in Figure 4. They then observe the subsequent transient response through vestibular feedback from the motion, through visual feedback from the outside world display, and through the highlighted instrument readings on the instrument panel shown in Figure 5. The effect of the auto-throttle is also sensed through audio feedback of engine RPM.

At the conclusion of the simulation session, design documents are made available regarding the design of the good and bad control solutions for students to use for comparison to their own design procedure as a means of reflective reinforcement learning.

Table 3
Typical instruction sequence for flight simulation exercise

Scenario 4: Closed Loop – Vertical Speed mode engagement with Auto-throttle – constant airspeed climb	
Instruction	
1	Set 1000 ft/min in the V/S command window using the thumbwheel.
2	Sim will be started. Engage the vertical speed autopilot by lifting the 'DISENGAGE' bar, pressing an autopilot button (L will suffice) and then press the V/S button.
3	Engage Auto-throttle as quickly as possible as too much airspeed loss will be difficult to recover. Engage the auto-throttle by lifting the 'A/T ARM' toggle switch and by pressing the 'SPD' button on the MCP panel. Observe the airspeed to settle at 150Kn.
4	The aircraft will enter a climb. Check for any enduring steady-state error in Indicated Airspeed (IAS) or Vertical Speed (V/S). Take note of the transient behaviour of the V/S needle in reaching 1000ft/min – speed of response, amount of overshoot.
5	Observe the airspeed response – the aircraft will initially lose speed as the thrust increases but it will recover to 150Kn. Note rate of speed loss and amount of overshoot as it reaches the target IAS.
6	Sim will be put on hold (re-set initial condition). Disengage the autopilot by lowering the 'DISENGAGE' bar and switching off the 'A/T ARM' toggle (down).

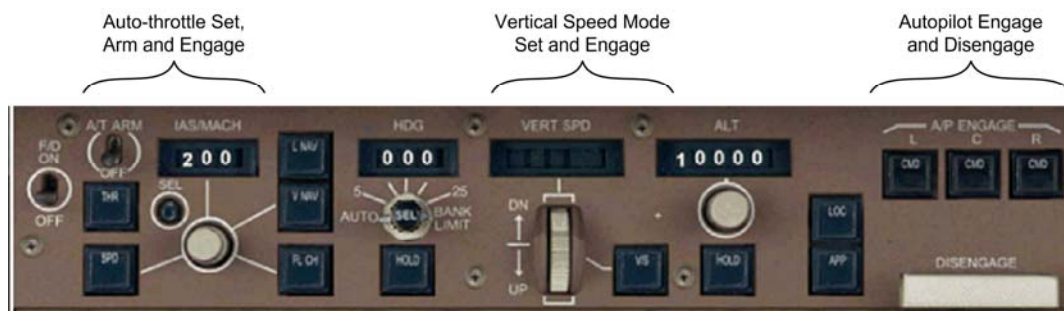


Figure 4: Autopilot Mode Control Panel (MCP)

CDIO-CENTRIC CURRICULUM (RE)STRUCTURE

In order to expand the CDIO-based experiential learning experience in the aerospace engineering education at The University of Sydney, the curriculum has recently been restructured. The revised curriculum, which will be implemented from the next academic year onwards, aims for a tighter integration of the various aeronautical units of study to reinforce the links between the different disciplines and to enhance the understanding of the intrinsic tight coupling of all disciplines in the conception, design, implementation and operation of aircraft. Figure 6 schematically represents the links between several units of study in the revised curriculum. The arrows on the figure indicate the flow of knowledge, learning experiences and specifications for the combined design exercises.



Figure 5: Typical instrument panel showing ASI, AI, VSI, ALT and DG instruments

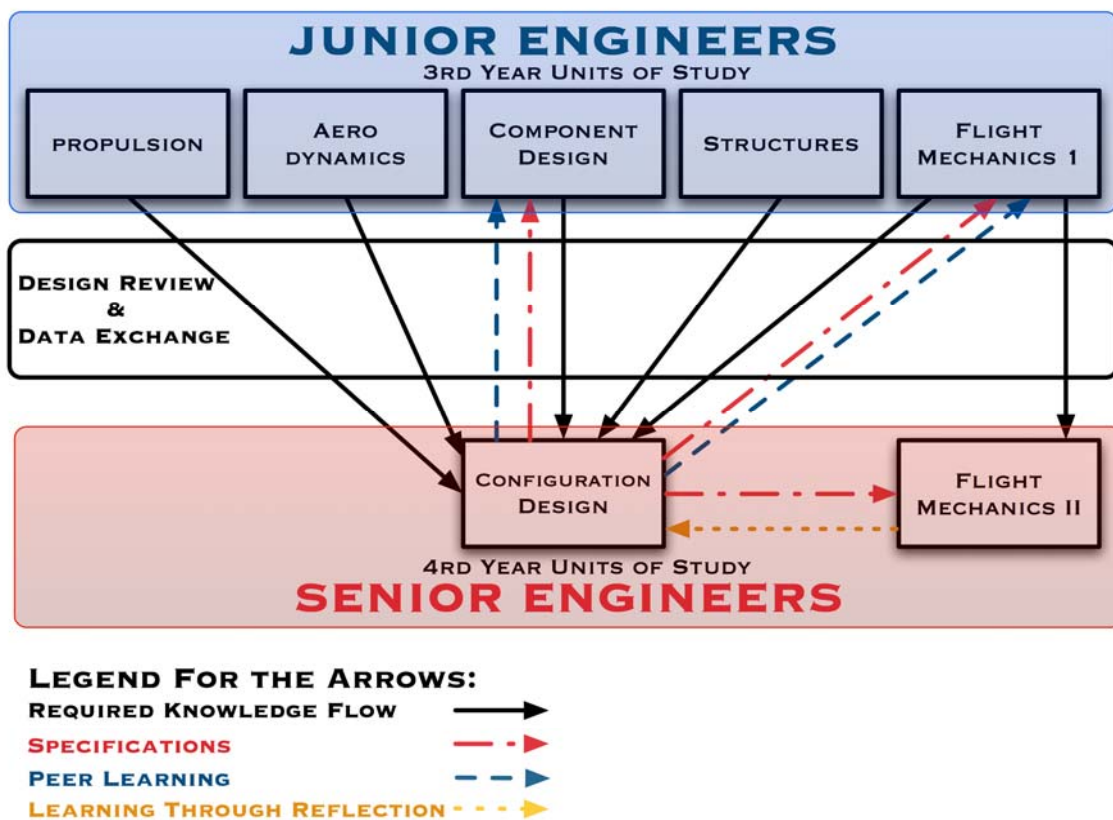


Figure 6: Flow chart of the "junior/senior" units of study in the revised curriculum

As shown on Figure 6, some of the third and fourth year units of study are organised as a junior/senior engineering experience to better match the university environment with the future work environment of our students. Due to practical and semester limitations, several of the third year units of study only serve the traditional role of providing required knowledge (indicated by the black arrows on Figure 6). A much closer interaction has however been set up between the third year component design and flight mechanics unit of study and the fourth year capstone configuration design and flight mechanics unit of study.

During their capstone design project, the “senior” engineers outsource the design and analysis of some aspects of their aircraft to the “junior” engineering component design teams by providing them with the detailed specifications that are required for the particular analysis (as indicated by the red arrows on Figure 6). In order to better understand the specific nature of the process, a short description of the contents and procedures of the design units of study involved in the close collaboration is given in the next subsection. A very succinct overview of some of the other prerequisite courses is given too. The details of the specifications exchange are then given in the following subsection.

Unit of study descriptions

The third year propulsion unit of study (AERO3261 – Aerospace Propulsion) provides the students with an overview of the different types of engines used on aerospace vehicles. Students are introduced to the performance of turbojet, -prop and -fan as well as rocket engines. The aerodynamics unit of study (AERO3260–Aerodynamics 1) covers both 2D and 3D subsonic aerodynamics as well as airfoil theory. Two other third year units of study are considered prerequisites for the capstone design course. In Aerospace Structures 1 (AERO3360), students are taught stress, strain, and displacement relationships for thin walled beams as well as shear panels, ribs and cut-outs. Bending and torsion effects are covered and energy methods are introduced. The Aerospace Technology 2 unit of study (AERO3465) on the other hand covers fatigue and damage tolerance of shear flow dominated structures. The students design a wing box structure for a given load set under tight weight constraints. The wing box is designed, built and tested to destruction, which allows a comparison between the calculated and the actual load carrying capability.

The third year component design unit of study (AERO 3460–Aerospace Design 1) introduces the students to practical detailed design projects of non shear stress dominated structural components. Throughout the course the students work on 3 major design problems of varying degrees of complexity. For the first assignment/design project of the unit of study, the students need to investigate the structural integrity of a camera mount and design the attachment fittings of the different components of the mount. The mount consists of a steel boom held in place with two aluminium struts, mounted on the roof of the cockpit. In a follow-up assignment students are asked to identify more suitable materials for the boom and the struts. In a second project, the complexity of the component is increased and detailed load cases for an engine mount of a motored glider. The mount is designed and analysed completely and a simple mock-up is built out of straws to assess the functionality of the design. The third design project of the course consists of a specific component of one of the fourth year configuration design projects as detailed in the next subsection.

The fourth year configuration design unit of study (AERO 4460–Aerospace Design 2) is set up as a completed aircraft design competition for student design teams consisting of 5 to 6 members. As in most capstone design courses a request for proposal (RFP) is provided to the students and each of the teams creates a unique aircraft design that meets or exceeds all of the requirements of the RFP in a competitive environment. The RFP is intentionally set up so that creative designs are needed to be able to meet the specified requirements boosting the students to think “outside the box”. During the course of the unit of study there are 3 major decision gates that are intended to represent industry design practices. After

roughly a third of the semester, a preliminary design review is organised where each of the teams present their configuration/concept, the main innovative aspects of their approach and how these help them meet the requirements of the RFP. At the two-thirds mark, an intermediate design review is set in place where design details are presented for some of the major components. Finally, at the end of semester, a critical design review is held. At this point each team presents their final design to peers, faculty, and industry guests. Each of the reviews serves multiple purposes. First of all they stand as milestones for the project development. They furthermore allow students to gain experience with professional public speaking and finally force students to defend their work against criticism. At each review milestone the teams hand in a report and give a presentation.

Specification exchange between the units of study

As indicated previously and as shown on Figure 6, some of the detailed analysis work of the senior capstone design project is outsourced to the junior teams. This setup provides several mechanisms to engage in deeper learning and reinforces the strong focus on both experiential learning and CDIO in the aeronautical engineering education in The University of Sydney. It furthermore leads to a much closer resemblance between the university environment and the future industry environment our graduates will work in. Not only will they be experienced in the industry practise of junior and senior engineers, the students are also exposed to the procedure of outsourcing and delegating work to a subordinate design team, which is more and more becoming common practise in the current highly specialised and global aerospace industry. Finally, the students are also trained in writing out detailed specifications for other teams.

The primary aim of the closer integration of different units of study is to enhance learning by offering several opportunities to promote the so-called deep learning approach. As the fourth year students guide the third year students throughout their work on the outsourced components, a significant amount of peer learning is embedded in the process. This process works both ways, as the third years will also question the choices that lead to the particular configuration of the aircraft they are analysing and designing components for in order to understand the nature and details of the specifications provided to them. This will serve as an additional review in the capstone design unit of study and will force the fourth years to justify their selection and hence promote reflection. Finally, as the fourth year students use the aerodynamic parameters of their own aircraft from the capstone design unit of study to develop a stability augmentation system and autopilot in the final assignment of flight mechanics II, a mechanism of reflection is introduced between the two units of study.

The specifications that are passed between the senior and junior team require a substantial amount of detail to allow the junior teams to work out their component design or stability analysis respectively. The senior team who writes out the specifications is as such responsible for providing all the required information in a suitable format. The specifications that are passed on to the groups for the component design course consist of geometrical details of the different mounting points of the structure to be analysed as well as all the load cases that need to be considered to comply with the appropriate FARs. Examples of structures that are analysed by the juniors are struts for a high wing strut braced general aviation aircraft or cantilevered spring type main landing gear. For the data exchange with the flight mechanics unit of study, the senior students have to provide all the aerodynamic parameters for a critical condition in the flight envelope.

Additional CDIO opportunities in the revised curriculum

Figure 7 illustrates the functional interactions between the primary units of study in design and flight mechanics. It highlights the key areas in which the Conceive, Design, Implement and Operate functions are distributed amongst the units of study. It also summarises the

nature of the key design data that are created and how they are exchanged and implemented in this scheme. When the different component specifications are exchanged between the third and fourth year students, the third year students are exposed to the conception and development phases of the capstone design course before they implement and operate their own part of the particular design. The interactions with both the third and fourth year flight mechanics units of study allow both student groups to implement and operate the aircraft they have worked on and fly it real time in the VSFS. These interactions between fourth and third year groups take on the added feature of providing a forum for students to be subjected to realistic design specification/review processes typical of industry practice.

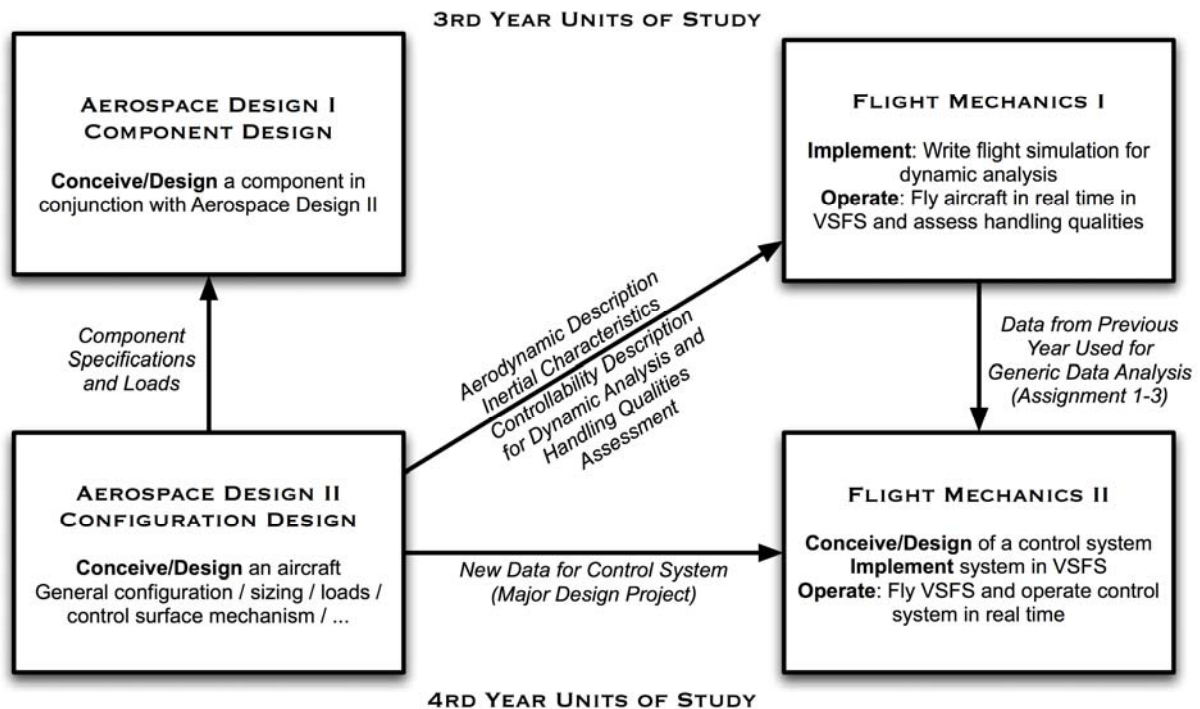


Figure 7: CDIO implementation in the design and flight mechanics units of study

CONCLUSION

A deeply embedded CDIO application has been established in which motion based flight simulation provides a real-time implementation and operation conduit for a capstone course in flight mechanics. The course involves the use of a specified aircraft's aerodynamic, inertial and controllability description to conceive and design stability augmentation and autopilot control systems for that aircraft. The resulting systems are implemented in the simulator and operated in real-time by the students as a means of reinforcement learning. It has been found that this immersive environment with a full complement of sensory feedback mechanisms is very effective in enhancing learning of the key concepts involved.

Building upon the success of this initiative, a broad based course curriculum has been formulated in which Aircraft Design units of study are tightly coupled with units in Flight Mechanics. The basic disciplinary content of junior units involving propulsion, aerodynamics and aircraft structures feeds into the capstone unit involving aircraft configuration design. The senior students conceive a complete aircraft configuration and specify component parts of their design to students in a junior unit of aircraft component design and facilitate a mechanism for design groups to undertake design review roles that closely mimic those

frequented by aerospace engineering contractors. The senior students assess the aerodynamic characteristics of their aircraft and use this description as the basis for their own autopilot design in their capstone Flight Mechanics unit of study. By this means students can undertake the complete design of a new aircraft configuration, including designing it for acceptable handling qualities and designing its flight control system. They are able to implement the aircraft dynamics for flight in real-time in the simulator with a full range of sensory feedback mechanisms to reinforce the learning. This key element of operation completes the learning loop and provides a strong link for reflective re-assessment and re-evaluation of their design experiences

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MODELING AND ARCHITECTING EDUCATIONAL FRAMEWORKS

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ABSTRACT

Nowadays, there are several program criteria that are proposed for accreditation. However, up to represent various accreditation bodies' requirements, diversity of disciplines, and specific national contexts, no global and unified framework for higher education has emerged. As such, the ability of educational organizations to work together is often hard to ensure. Following constructive alignment principles, an educational program relies on three main pillars: (i) an intended curriculum, (ii) a taught curriculum, and (iii) a validated learned curriculum. At the core of program descriptions, those three views share concepts, such as learning outcomes. To enable interoperability among existing programs and frameworks, and sustain flexibility and evolution of standards, it is relevant to clarify common core concepts belonging to various frameworks. A system modeling approach is obvious for meeting such interoperability challenges, since it makes it possible to meaningfully, unambiguously, and accurately specify concepts, relations, and viewpoints among stakeholders.

The CDIO Initiative celebrates its 10th anniversary by proposing today a mature integrated framework for engineering programs. Structured in twelve standards, it permits to create, to reform, or to continuously improve engineering educational programs. It encourages introducing appropriate pedagogical methods and also addresses student workspaces and staff workforce. Based on the CDIO standards as a proof of concept, this paper proposes to model three views based on structural diagrams. Significant relations between educational concepts are then defined. Furthermore, getting its inspiration from an architectural approach, this paper significantly contributes to lay the foundations of an architectural meta-model for describing complex educational systems, which will contribute to tackling interoperability and flexibility issues.

KEYWORDS

Educational frameworks, constructive alignment, sustaining curriculum reform, facilitating change in engineering education, application of CDIO to a wide range of disciplines.

INTRODUCTION

Transformation of educational programs plays a recurrent and key role in the future of an institution (e.g. school, university). It impacts its operating modes, its quality and its future performance. The management of educational systems (e.g. programs, workforce, workspaces) is thus of strategic importance. As such, during the last decade, various initiatives on quality management models and educational frameworks have spawned, proposing a class of standards that allows educators and program leaders to evaluate and improve their various curricula, services and resources. However, their increasing complexity requires different types of expertise from various stakeholders (e.g. program designers, managers). Moreover, complex processes are involved in these initiatives, some of which are not always well described and controlled.

To prepare the next generation of engineers, the 12 standards of the CDIO educational framework offer many keys for reforming or continuously improve engineering programs. Representing much more than a simple syllabus organizing learning outcomes, they form a multidimensional educational constellation addressing several stakeholders' issues (e.g. hints on workspaces, curriculum integration, learning styles, faculty development, assessment and evaluation). Nevertheless, to maintain the pace with the evolution of societal and educational environments and missions, the CDIO framework should remain a dynamic tool: Firstly, the framework itself may need to be updated (e.g. see recent changes of standard #2 syllabus relating to sustainability, leadership and entrepreneurship issues [1], interrogations on a 13th standard, etc); Secondly, educational institutions must often adapt the CDIO framework to their own reality dependant on quality requirements (e.g. criteria defined by professional or governmental accreditation boards, specific quality management models); Lastly, business constraints (e.g. costs) and incitements to collaborate more and more formally with potential partners (e.g. for deeper visibility, ratings and rankings, student exchanges, etc.), sometimes drive educational institutions to juggle with various educational systems, or even frameworks [2], at the risk of creating inconsistency and interoperability problems.

Following constructive alignment principles [3], based on objectives, teaching and assessment viewpoints, this paper identifies key concepts for modeling educational systems. By proposing three sound models, it contributes structuring unambiguously relations among those concepts. Derived from an analysis of the CDIO standards from conceptual and structural perspectives, and inspired by best practices of modeling [4], it reveals accurate semantic relations among these three models. Based on multiple views, it thus permits to clarify, at an abstract level, the now complex CDIO instance. Furthermore, getting its inspiration from a standardised complex system architecting approach, this paper highly contributes to lay the foundations of an architectural meta-model (i.e. highlighting concepts and properties of the domain models) for educational systems and which could address, more holistically, interoperability and flexibility among educational frameworks.

This paper is structured as follows. After the introduction, some existing notations for educational modeling are surveyed. In the next section, based on the CDIO standards as a case study, three conceptual and structural diagrams for constructive alignment are proposed. They correspond to educational program pillars: (i) an intended declared curriculum model, (ii) an enacted taught curriculum model, and (iii) a validated learned curriculum model. It is herein argued that several of the CDIO standards could be regarded as resources, properties or constraints in such system models. Relations between these models are then derived at the end of this section. Following section examines the benefits of educational system modeling for various stakeholders, and presents the requirements for constructing viewpoints that cover dedicated concerns. Before concluding and providing some perspectives, the last section reviews some quality management models in education so as to pave the way for future work on behavioural educational modeling.

MODELING EDUCATIONAL FRAMEWORKS

As the complexity and size of educational systems increase, accuracy emerges as a problem. Some equivocal terms are used, sometimes without common understanding. Thus, it is a major concern to describe and share unambiguously common concepts among the various stakeholders involved in a program design or transformation. In such a context, modeling approaches permit to represent, visualize, and document the artefacts of a system. In fact, models [4] permit to unambiguously and consistently describe concepts and their relations. Among other benefits, by minimizing ambiguities and introducing some formality, they favor better understanding, coherency, alignment, analysis and (re)usability of informal principles and recommendations.

Educational Modeling Languages

Several notations or languages exist for educational modeling. Martinez *et al.* classifies education modelling languages in three categories [5]:

1. Content Structuring Languages, which allow designers to arrange the learning resources in sequences, always taking into account the learner's needs and performance in order to improve the learning experience;
2. Activity Languages, which focus on the activities in general during the learning process;
3. Evaluation Languages, which allow designers to describe the stages of the learning process, in which problem-solving or question-answering are involved, in an abstract way.

In the last decade, Rawlings *et al.* define the Educational Modelling Language (EML) as: "a semantic information model and binding, describing the content and process within a 'unit of learning' from a pedagogical perspective in order to support reuse and interoperability" [6]. In this context, EML is used to describe units of learning, including the operational flow of learning activities. Directly associated with learning management systems and used for creating online learning activities, such modeling languages are far from being manageable by non expert stakeholders involved in a holistic educational framework, as they are mainly addressing low level metadata in files for interpretation and processing by software engines. Note that some more fined grained notations have been introduced for modeling educational units or activities [7], but they are outside the scope of the proposals of this paper.

The Unified Modeling Language

Initiated for software engineering purposes, the Unified Modeling Language (UML) [8] is the accepted standard for specifying and documenting software systems. Due to its expressive strength and relative simplicity, it is more and more used to create visual models other types of systems (e.g. in engineering, information or enterprise systems, or even business and finance domains). As such, it is also a very good candidate for educational system and framework modeling. Several notations are proposed in the arena of UML to create diagrams, in two distinct views.

UML Structural View

Several structural modeling diagrams are used for defining the building elements of a model, but also for describing their relationships and dependencies. Figure 1 sketches the basic notations proposed in UML class diagrams which will be used in the various proposals of this paper:

1. The first *Association* relation, represented by a link, means there is a connection between two concepts. In the example (cf. the top of the figure), there is one *AConcept* which is associated with one *AnotherConcept*. An annotation or verb can be attached to the link. The cardinality of the association is here of type 1-1;

2. Associations can support multiplicities, on one end or on each of the two ends of a link. For example, the second relation of the figure specifies that *ContainingConcept* is associated with zero or more *ContainedConcepts* (cf. '*' multiplicity). Each *ContainedConcepts* has to be of the same type, but has a different instance. By default, if there is no multiplicity specified on a link, it is considered 1 (as in the first relation); Multiplicities can also be of type 1..*, if at least one *ContainedConcept* is required;
3. The third and last relation in the figure, *Inheritance*, means that *SubConcept* has all the properties of *SuperConcept*. *SubConcept* can have new properties, which *SuperConcept* did not have, and can redefine properties inherited from *SuperConcept*. Note that the direction of the arrowed link is of importance.

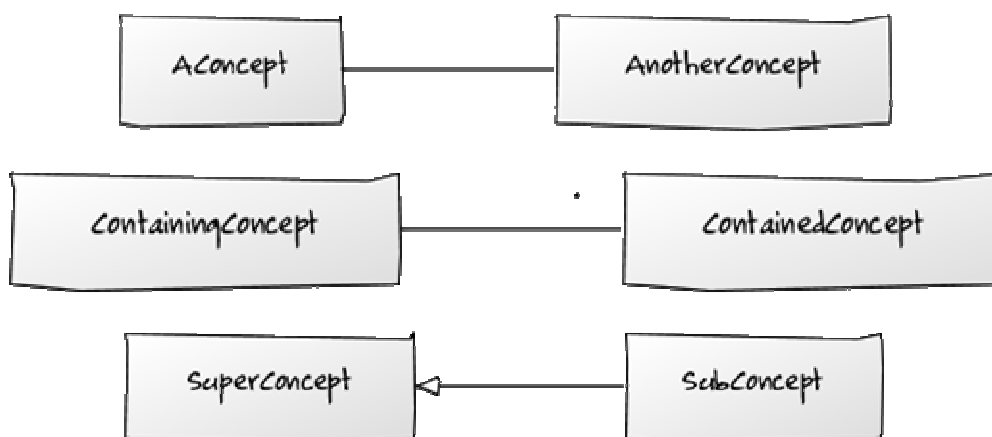


Figure 1. Basic relations between concepts for structural modeling in UML.

Behavioral View

Behavioral diagrams make it possible to capture the varieties of interactions among elements, their inputs or outputs, and their states and dynamicity over time. To model this, among others, UML proposes use case diagrams and communication diagrams. Temporal models could have been introduced as well (e.g. UML activity diagrams or by using other dedicated business process modeling notations, like BPMN [9]). In fact, educational processes, e.g. like student recruitment, pedagogical development and deployment, course or project unit design and implementation [10], require specific behavioural notations. However, only structural views will be considered in the rest of this paper.

STRUCTURALLY MODELING AN EDUCATIONAL FRAMEWORK: CDIO CASE STUDY

Constructive alignment [3] clarifies the design of curricula and sheds light on the association and alignment among intended learning outcomes, taught curriculum (including learning activities) and assessment. Harden [11] also clarifies that a curriculum is not limited to course contents. It can be decomposed in views using (i) an intended declared curriculum model, (ii) an enacted taught curriculum model, and (iii) a validated learned curriculum model. These three models share common concepts, learning outcomes is one which is addressed by all these three perspectives.

When numerous concepts are interconnected, e.g. from structural or behavioral perspectives, the notion of integrated curriculum [12] facilitates coherency among many sub-elements. As such, the next subsections propose structural diagrams for three CDIO standards to further highlight conceptual relations between these models from a more global point of view.

Modeling CDIO Standard #2: “Syllabus Outcomes”

The intended curriculum (or declared curriculum) most often addresses concepts including learning outcomes, knowledge and skills (sometimes attributes). As in the CDIO Standard #2, these concepts are rarely left alone; they are most often associated with each other. The concepts and associations can be represented in a diagram as abstractly proposed in figure 2, where a *Syllabus* is composed from 0 or more *Learning Outcomes* (cf. “*” multiplicity between the two concepts). There may be *Optional Outcomes*, described through the inheritance relation between *Optional* and *Learning Outcome* concepts. A learning outcome is associated with 0 or more *Activity Domains*, *Core Knowledge* and *Skills*. For the CDIO syllabus, there are several types of *Activity Domains*, modeled through the inheritance relation with *Operating*, *Implementing*, *Designing*, and *Conceiving*. Skills as well, can be *Interpersonal* or *Personal*, by inheritance. A program, conforming to such a model, could be checked for completeness, e.g. with the CDIO syllabus or EQF/EUR-ACE [13].

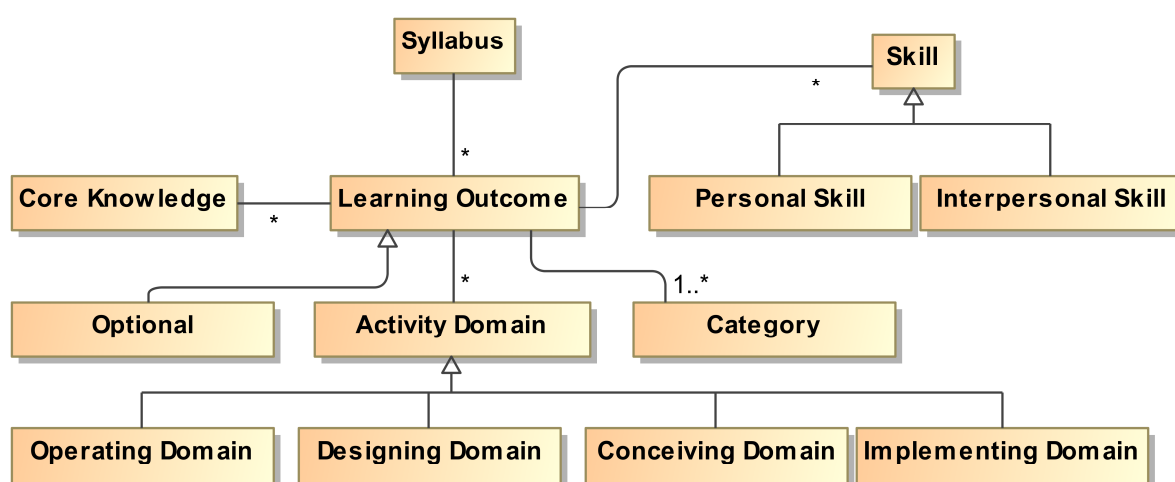


Figure 2. Intended curriculum diagram.

Note that in the proposed model of figure 2, categories could have been associated with learning outcomes, for example, Bloom or Anderson & Krathwohl cognitive and knowledge dimensions, or even EQF descriptors.

Modeling CDIO Standard #3: “Integrated Curriculum”

The taught curriculum (or enacted *Program*) supports the declaration of *Courses* and associated *Activities* as defined in a program booklet. By relying on the CDIO Standard #3, where a *Program* contains several courses, its concepts and associations can be represented in a diagram as proposed in figure 3. By inheritance, there are different types of courses, *Core*, *Introductory*, *Major*, *Minor*, or *Elective*. A *Course*, whatever its type, could contain several *Activities*, which, by inheritance, can be of type *Tutorial*, *Laboratory*, *Project*, *Lecture*, *Seminar*, etc. More structural description details can be provided, e.g. by inheritance, a *Project* concept could be refined with e.g. *Introductory Project* or *Capstone Project*. An *Activity* has several *Resources* allocated, which can simply be of type *Room* (e.g. workspaces), and/or *Teacher*, etc. If necessary, *Activities* can be associated with *Learning Styles* (e.g. instructive, problem-based learning, etc.). *Extracurricular Activities* and *Internships* are also possible part of a *Program*.

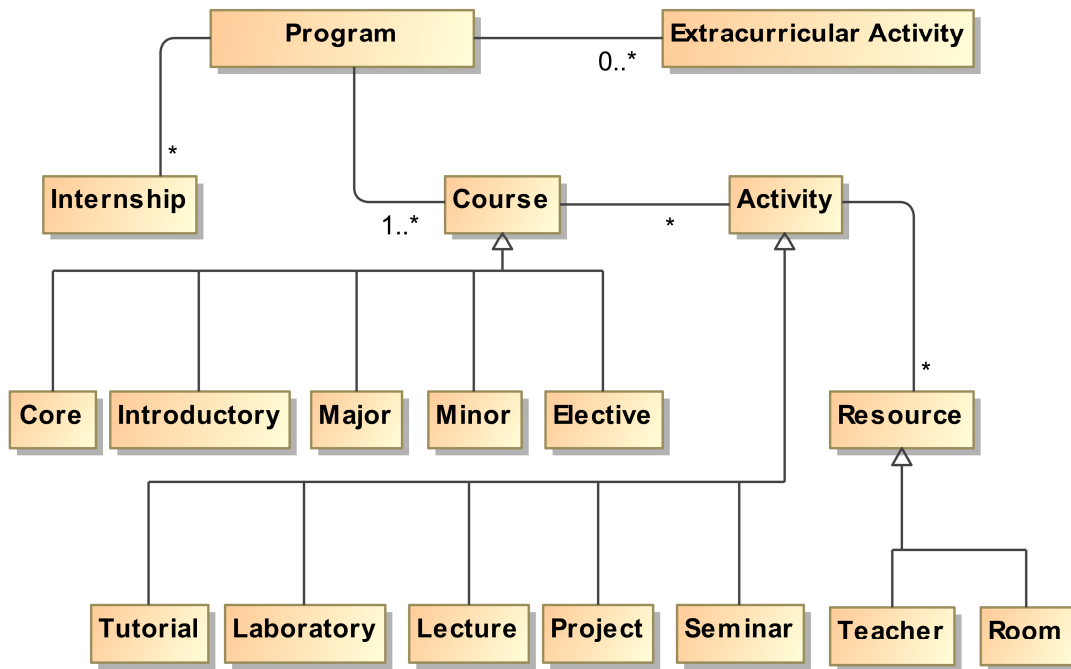


Figure 3. Taught curriculum diagram.

Modeling CDIO Standard #11: “Skills Assessment”

The validated curriculum (or learned curriculum) clarifies the assessment activities, which could be of various types [14]. Following some of the recommendations of CDIO Standard #11, the concepts and associations can be represented in a diagram as proposed in figure 4. Types of *Assessment*, which can be *Exam*, *Oral Presentation*, *Report*, *Portfolio*, *Interview* or *Moral* are described. An *Assessment* may have several *Forms*, which can be *Formative* or *Sumative/Informative*. *Assessments* are classically associated with a *Proficiency Level*.

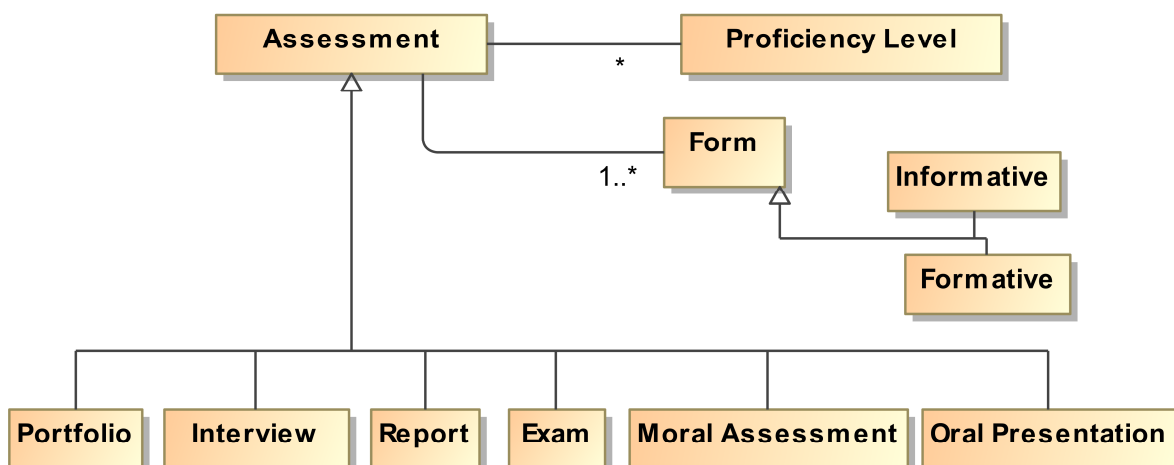


Figure 4. Validated curriculum diagram.

What about the Other CDIO Standards?

We propose three diagrams as a graphical representation of curriculum's models. However, a model also contains elements of documentation that clarify the concepts and diagrams (e.g. properties, design rationale). We have seen that a curriculum can be described through three views following a structural approach. In integrated educational frameworks, several other

guidelines are also provided. In our opinion, the other CDIO standards could be taken into account as follows:

1. Standards #4 “Introduction to Engineering”, #5 “Design-Build Experiences”, and #7 “Integrated Learning Experiences” are mainly constraints or properties (as good practices to follow) for the taught curriculum model;
2. Standard #8 “Active Learning”, as a specific pedagogical style, is to be associated with activities of the taught model;
3. Standard #6 “CDIO Workspaces” is also a set of properties/constraints for the enacted taught curriculum, mostly associated with resources (cf. *Rooms*);
4. Standards #9 “Enhancement of Faculty CDIO Skills” and #10 “Enhancement of Faculty Teaching Skills” are specific, since they are not directly associated with the curriculum. However, as part of an other view, they share concepts like the syllabus and participate e.g. in the *Teacher* concept as resources in the enacted taught curriculum;
5. Standard #12 “CDIO Program Evaluation” is quite orthogonal with the other standards, even if it could be integrated as a learning activity. Its behavioral models (e.g. process) are of importance for continuous improvement, but are not addressed so far in this paper;
6. CDIO standard #1 “CDIO as a context” can be seen as principles to follow, a mission statement. It will be discussed in the following section on architecting educational frameworks.

Relations among Models

Proficiency Levels and Categories

The connection between the first intended (cf. figure 2) and the third validated (cf. figure 4) curriculum models consists in the fact that the *Assessment* concept determines the *Proficiency Level* which a student has achieved for a *Learning Objective*. To measure this level, predefined standard scales are needed, e.g.:

- The European Qualification Framework (EQF) introduces eight reference levels [13]. It covers the full range of qualifications generally acquired, including vocational/academic education and training, from basic levels (e.g. Level 1 for school leaving certificates) to advanced levels (e.g. Level 8, for Doctoral degrees). Here also, each level is described in terms of learning outcomes.
- Bloom categories, or dimensions, could be addressed as well if present in the intended model as discussed earlier.

With such categories specified, model transformations could be provided to switch from one category to another [2].

This relation is depicted at the bottom left of figure 5 (in red), with an ‘1..*’ multiplicity on both end. The *Assessment* concept of the third validated model can be associated by inheritance with the *Activity* concept of the second taught model, since it is a part of a course (cf. bottom right in the figure).

Curriculum Maps

Learning outcomes of the intended model are also associated with activities of the taught model. As two dimensional matrixes, simple curriculum maps are used as a visual representation to associate intended and declared curriculum [11]. Classically, course codes are listed in a first -possibly temporally ordered- axis, and higher level learning outcomes are listed as a second axis -also possibly ordered. Proficiency or degree level expectations can be introduced on intersections when a course addresses a specific learning outcome. Curriculum mapping facilitates transparency among stakeholders and favour completeness and coherency issues of learning outcomes throughout the declared curriculum.

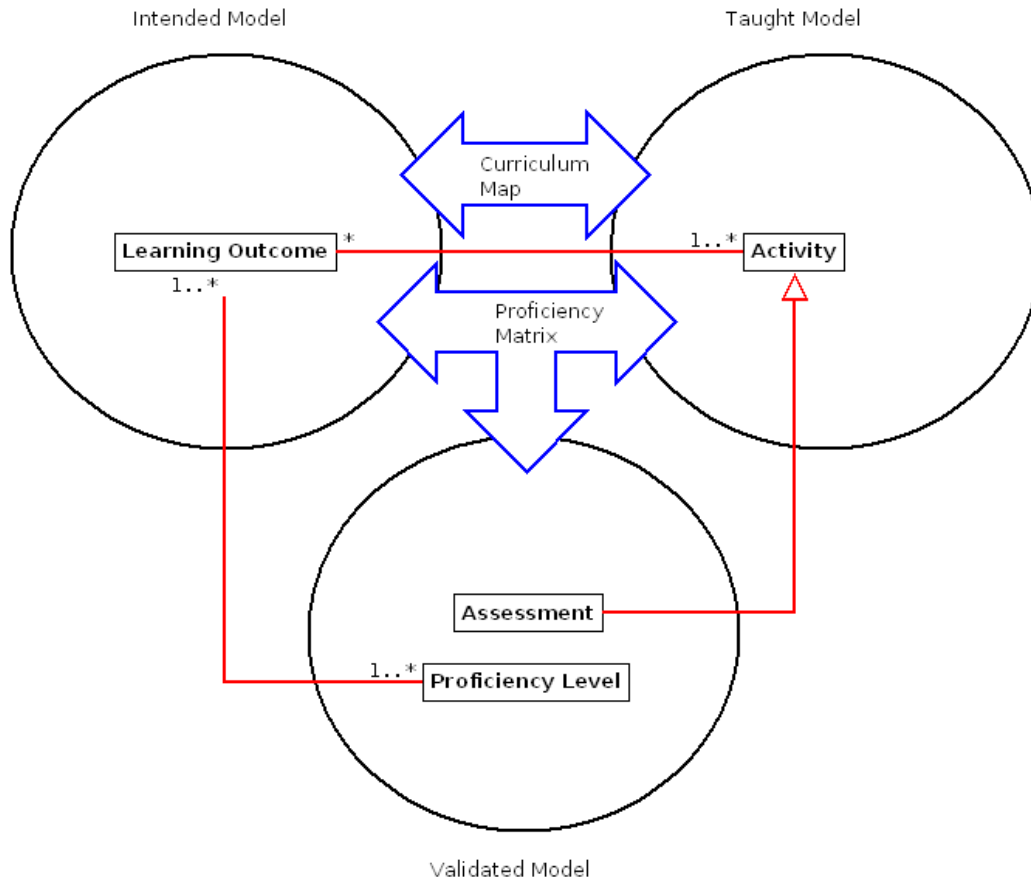


Figure 5. Concept associations among models.

Proficiency Matrixes

By associating curriculum mapping and *Assessment* concept, thanks to the relations among the various concepts, it is possible to establish a three dimensional matrix including the effective proficiencies of learners. Figure 6 presents such a matrix, with courses and professional experiences from the second taught model in rows and classified learning outcomes from the first intended model in columns. A sub-matrix is zoomed in the left upper part of the figure, including declared proficiency levels from the validated model (using a five-color scale). As such, the three models have permitted to transitively associate concepts which could form the cornerstone of an integrated curriculum.

ARCHITECTING EDUCATIONAL FRAMEWORKS: STAKEHOLDERS VIEWPOINTS

To manage the various proposed concepts and models in a unified manner, following an architectural modeling approach is the key. As proposed in the IEEE 1471 recommended practice [15], a system is best documented via its architecture. Generally speaking, a system could be an enterprise, a service or product, a system of systems, etc. From a system perspective, an educational system conforms to a meta-model, highlighting concepts and properties of the domain models. It exists within an environment which influences it, and fulfills one or several missions (e.g., as found in the CDIO standard #1).



Figure 6. Learner proficiency matrix example
-including 64-experiences/courses (rows) x 113-capacity (columns)-
with categories and blocks (developed by a candidate for graduation), from [16].

A well organized educational framework prompts architecture. The *Architecture* of an *Educational System* (concept in red in top left of the figure 7) is described by a unique - ideally unambiguous- *Architectural Description* (seen as the concrete description). Above all, the architectural description is organized by several *Views* (conforming to *Viewpoints*). To participate in one or several view, we propose to describe an educational system with an aggregation of the three presented curriculum models (concepts in red in the down right of the figure). These three models enable constructing the overall educational system description, which should conform to properties and constraints (e.g. learning styles, introductory elements or advanced level experiences, workspaces).

Several concepts, such as *Stakeholders* and *Concerns* are also proposed. A stakeholder has interests in one or several concerns. Taking inspiration from such an architectural approach, by investigating various *Models* and stakeholders' *Views* for engineering complex educational systems, a set of reference *Viewpoints* would be largely beneficial, particularly because of the large number of stakeholders involved, e.g.:

- students,
- faculty and program managers,
- employers of graduates,
- educators, instructors and external teachers,
- educational researchers,
- governmental and industrial accreditation boards, and industry representatives,
- internal quality assurance managers,
- alumni, parents or K12 secondary students,
- partners, potential investors, sponsors, etc.

Each *Viewpoint* is used to cover several *Concerns*. As an example, a program or course datasheet (and the same is true for as for curriculum maps, proficiency matrixes) has multiple roles, sometimes contradictory. Indeed, such datasheet is a shared tool between the education services and the program or course managers, between teachers and students, between the institution and the public in search of information details on contents, but also between the school/university and the accreditation bodies. All these stakeholders have various concerns and do not necessarily have to be aware of all the subconcepts, constraints and details in a unique model.

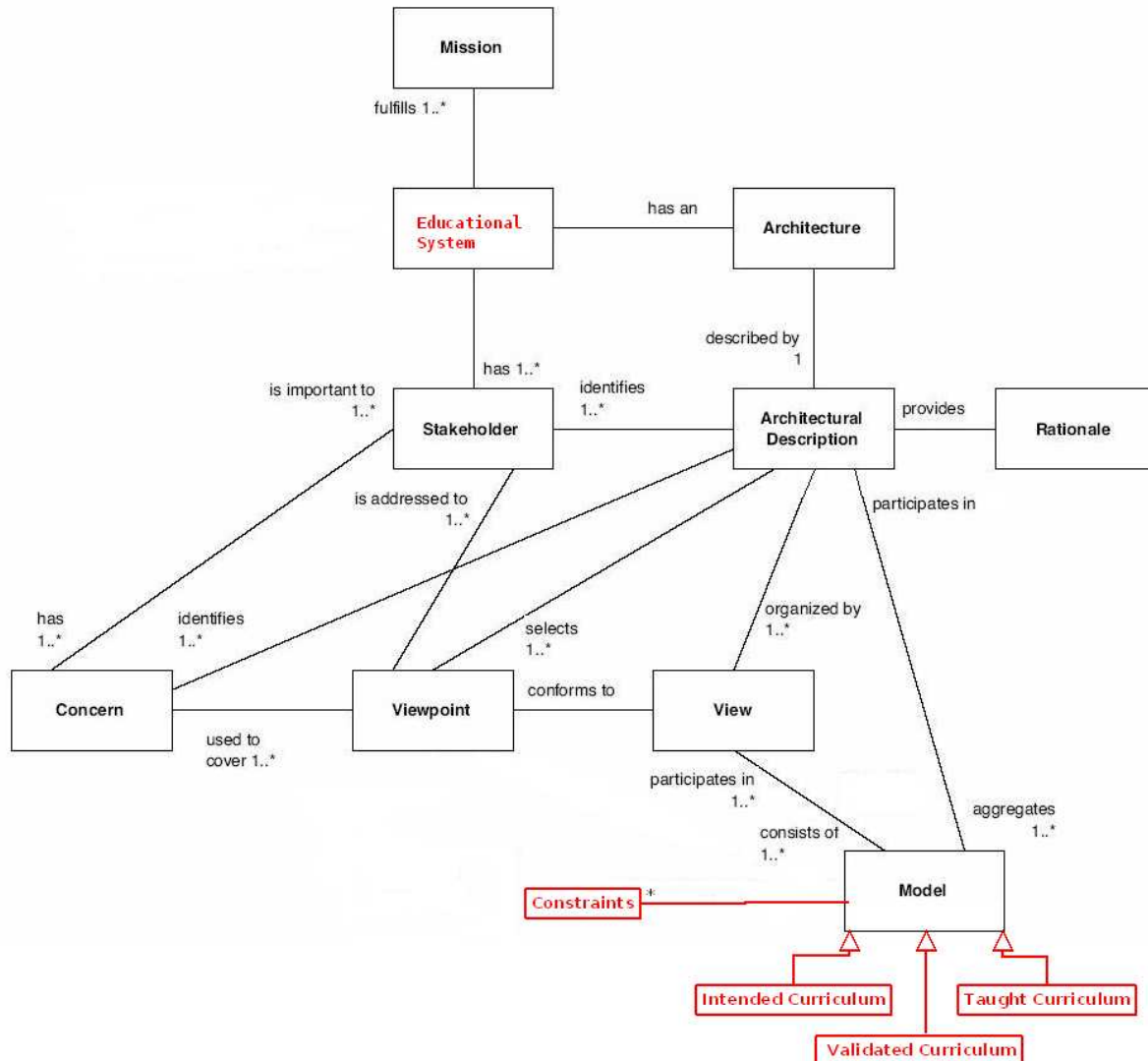


Figure 7. IEEE-1471 system overview meta-model, slightly revamped for the educational context.

QUALITY MANAGEMENT IN EDUCATION

Models are also addressed in quality assurance. From a business process management point of view, even if the mission of education is not only service-based but also information-based (e.g., as knowledge), an educational institution principally provides educational programs and services. Through the definition, analysis and optimization of their processes, engineering educational institutions are nowadays more and more requested, by professional societies or governmental regulations, to meet quality standards [17]. The management style of higher education has been discussed for several years, and is still controversial [18]. It is

often said that in order to manage a transformation project and to continuously meet quality requirements, two distinct disciplines are to be mastered: engineering (e.g., design, conceive, implement) and management (e.g., plan, decide, communicate, control). Some higher education institutions are turning to total quality management models, sometimes following corporate style management, so as to support deep improvement opportunities.

Corporate Style Quality Management in Education and Performance

In broad lines, if seen as an enterprise, an institution has one or several missions defined, inhabits an environment, and possibly has to conform to various constraints. It will be seen as a provider of value to its clients/customers (e.g. students, employers, future entrants). With this perspective, an institution principally proposes as product an educational program with associated services. Among other stakeholders, the student is finally the main customer, with requirements and expectations.

Several models of quality management in education have appeared pursuant to such a corporate style [19]. For example, the Malcom Baldrige Performance Excellence Program, managed by NIST, proposes education criteria for performance excellence [20]. Customer (e.g. students, stakeholders) and workforce focus are addressed in categories of the corresponding quality framework pursuant to a system perspective. Other categories are leadership, strategic planning, knowledge management, operation focus and results. As another example, the European Foundation for Quality management (EFQM) Excellence Model [21] has followed a business model. Several concepts underpin EQFM, i.e. result orientation, customer focus, leadership, management by processes and facts, people and partnership development, continuous learning, and corporate social responsibility. This model also focuses on what an organization could do to produce a better service or product for its customers, or service users, as well as stakeholders. The model is based on five key enablers of improvement: leadership, people, policy and strategy, partnership and resources, and processes.

The various propositions and results of this paper are more formal and structured than the two above-mentioned and explicit more precisely the alignment among views. However, for the moment, they are limited to structural models and do not address business processes and planning.

Business Process Vision

Following a business process management vision, an educational institution executes declared processes, using as inputs external and internal values (e.g. external from partners, suppliers, internal from staff and workforce) and consuming/using resources. To improve quality and remain valuable, an institution should understand its customer needs and design processes so as to meet their requirements. It is even more the case when customers, such as students, participate as actors in several of those activities, in interaction with resources. However, to explicit business and operational processes among stakeholders, and minimize ambiguities, behavioural specification languages are very welcome. To this effect, and to favor continuous improvement, educational institutions could rely on an integrated approach aiming at modeling their processes, collaborations, or their infrastructures (e.g. physical and human resources, information systems [22], etc.), as well as some elements of their strategy and motivation. Being complex, and apart from the management activities, these engineering activities are also classically the responsibility of architects (e.g. designing processes and critical infrastructures for an institution's current and future operations), representing and documenting the whole educational system with models.

CDIO Program Assessment Approach Encouraging Well Managed Processes

Educational frameworks and requirements defined by accreditation bodies (e.g. ABET, EQF/EUR-ACE, Engineers Australia) tend also to address in their standards processes for better quality management. In the CDIO initiative, initially one generic rubric was used for program self-assessment (with a hierarchical scoring, scale from 0 to 5) to check conformity with the CDIO principles. In 2010, rubrics were specialized for each of the twelve standards. They all use a common scale for the ratings. The Standard # 12, on program evaluation, is CDIO's cornerstone of continuous improvement. As such, several methods could cohabit with the ones of accreditation bodies, and the CDIO self-assessment method of compliance is a complement to them. For systematic and continuous improvement at CDIO-levels 4 and 5, well managed processes are a key element. Nevertheless, at the maximum level 5, standards 2, 3, and 11 include evaluation by external groups. To ensure a regular and systematic review, as well as future recommendations for continuous improvement, models - including structural and process models- are here also a key issue for the various stakeholder groups with respective viewpoints.

CONCLUSION AND PERSPECTIVES

Educational frameworks are defined with varying degrees of rigor, and can thus lead to ambiguities among stakeholders having various concerns. To date, there is no standard and common accepted way of conceptual description for such complex frameworks. To answer this lack, the proposed approach in this paper shows the need for sound design methods to derive educational systems from high-level descriptions. The three proposed structural diagrams permit to describe and represent engineering education curricula more abstractly, so as to minimize ambiguities among stakeholders and sustain flexibility in change. Common understanding of concepts and associations can thus be achieved. Moreover, managing flexibility and interoperability between educational systems and frameworks most often requires a tortuous work. For example, coping with incompatibility in semester course periods for student exchange is sometimes a tricky task. But having modeled each of the interoperating programs rigorously, and checked conformance with a same framework model, inconsistencies can be readily detected and more correctly addressed. As a first step for achieving interoperability, this paper exemplified the approach, with the CDIO framework as a proof of concept.

Educational system design and transformation involve many stakeholders. The proposal also permits to unify multiple views through an architectural modeling approach. By constructing educational system architecture as an aggregation of several coordinated models, specificities, properties and constraints can be addressed more explicitly. Using the proposed approach, it is easier to understand the relations among shared concepts and minimize ambiguities. Coherency issues can be addressed early at design time, which stops them from propagating during operating phases.

Interoperability between Various Frameworks

Another benefit of modeling educational systems with an architectural perspective consists in addressing the interoperability issues among different standards at a framework level. For example, if the relations between concepts from the CDIO standard and concepts from the EUR-ACE standard are described at a meta-model level, then some of the relations between models could be established and validated for all models/instances which conform to these models. It is sufficient that they are described only once, and thus can be systematically applied on instance models specific to an institution. This facilitates co-operation among institutions using different educational standards or frameworks.

Towards Educational Specific Notations

In this paper, we mainly focused on the structural modeling aspects using a UML-like notation. However, to date, UML is a wide set of graphic notation elements and thus permits also to represent and visualize behavioral views such as activities and business processes, or actors of a system. An architectural modeling language offers the advantage of a unified language, capable of describing a wide range of domains. It makes it possible to aggregate models of the enterprise or educational constellation, which can be more easily understood by all stakeholders. While this is very useful from a conceptual, informational and structural perspective, more details are often needed to deeply describe a system. The unified modeling language used in this proposal could lack the semantic strength required (e.g. some temporal or behavioral issues).

To go further, an Enterprise Architecture modeling language development method proposes to use a unified modeling language at the business level (e.g. processes), while using domain specific languages and methods at more detailed levels [23]. Domain Specific Languages allow experts to express, validate, modify solutions and achieve tasks specific to their domain. They require less cognitive design efforts from experts than a more general purpose language [24]. Thus quality, productivity, reliability, maintainability, reusability can be enhanced. In the engineering education context, we can propose as future work to design dedicated and more easily understandable graphical languages to facilitate adoption for non UML experts. Through appropriate notations and abstractions, expressive power focused on this particular problem domain will permit to visualize, specify, construct and document an educational framework more easily for the education community. To benefit from these advantages, the diagrams proposed in figures 2, 3, and 4 may be confronted with educational designers to imagine a Domain Specific Modeling Language as a profile for an Educational Architecture modeling framework.

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Step Change Implementation of CDIO – The Aston University Story

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ABSTRACT

The aim of this paper is to provide a comprehensive account of the experience of Mechanical Engineering & Design (MED) at Aston University in adopting a system level implementation of the CDIO framework at EQF Level 4. This is Aston's first experience of CDIO and represents a step-change in learning and teaching philosophy from a long-established traditional engineering science didactic format. The paper describes the reasons for changing, the innovative teaching and learning practices that have been employed, how it has been implemented, and the experiences of staff involved during its development and practical implementation.

The account shows the progress that Aston has made in its first semester of implementation and details some of the cultural challenges it has faced, along with some of the unexpected benefits of improving learning and teaching practice. Through building engineering and design programmes around large 30 credit active learning modules based upon the CDIO framework Aston academics have found that early stage implementation has increased efficiencies in terms of reduced assessment loading by 54 % and reduced space utilisation requirements by 37 %. Furthermore the changes have been made without significant increase in workload beyond the creation of new learning experiences, and without sacrificing academic challenge. Successful implementation of the new CDIO based programmes have been demonstrated as being effective at increasing student engagement, creativity and problem solving in both practical, active learning sessions and conventional declarative knowledge learning sessions.

KEYWORDS

CDIO Implementation, reasons for change, efficiency savings, collaborative teaching

INTRODUCTION

In 2010 the Mechanical Engineering & Design subject group at Aston University (Birmingham, UK) significantly revised its taught programmes with regards to learning and teaching practice for all 1st year undergraduate students (European Qualifications Framework Level 4). Large active-learning modules based upon the CDIO learning framework were introduced into each semester around which all mechanical engineering and design programmes were based. The importance attached to this project based learning approach is reflected in the fact that this now accounts for 50% of learning and assessment activities at Level 4 and is supported by specialist science, maths and technical modules.

At the time of writing the first cohort of Level 4 undergraduates have recently completed the first CDIO based module and are about to complete the second. It was decided from an early stage that greatest flexibility in carrying out 'design, build, test' type CDIO activities would best be served at Aston using whole day sessions. While this offers many benefits it was also found to require careful management in terms of pace, activity levels and in ensuring an adequate balance between instruction, active and reflective learning.

Opportunity and Justification for Change

The Mechanical Engineering & Design (MED) subject group within the School of Engineering and Applied Science (SEAS) at Aston University has undergone radical change in the past 18 months. After bifurcating from former companion subject group, Engineering Systems and Management (ESM), MED was able to refocus on the needs of its core students without them being tempered by those of students on other programmes.

This, in conjunction with a period of staff turnover, gave the opportunity for consideration of the courses on offer and the development of fresh perspectives on the quality of the student experience, debate on how best to meet the needs of industry, and reflection on how the courses could better equip students with the skills for their professional careers.

Staffing at the time of course redevelopment stood at 16 full time equivalent academic staff and 9 technical support staff. Student distributions were approximately 100 per year of study with approximately 65-70 % of students residing on mechanical or design engineering programmes, and the remainder on product design programmes.

Review of the pre-existing 1st year programme

Biggs refers to conventional professional education as being one of amassing declarative knowledge of independent subject areas [1] which is an erudite description of the majority of traditional engineering degree programmes, and specifically those in MED. Following an instructivist pedagogical model material was delivered in a predominantly didactic lecture and tutorial format where students acted as passive recipients of knowledge [2] there was little opportunity for learners to develop the creative problem-solving, flexibility in knowledge application and interpersonal skills that are expected in graduates by the UK Engineering Council [3], and by industry leaders [4]. Furthermore, in order to address specific areas of declarative knowledge within a modularised structure there was a large number of low credit bearing modules (see Figure 1) with a heavy analytical or theoretical bias: 120 credits spread over 11 modules in 2 semesters at level 4, with a similar pattern replicated at level 5. Although this was administratively efficient, offering flexibility in timetabling and assessment, and permitting academics to deliver material aligned to their specialism, this resulted in a high assessment load for both staff and students with unavoidable parallel repetition of assessment types with limited opportunity for formative development in terms of group and technical report writing.

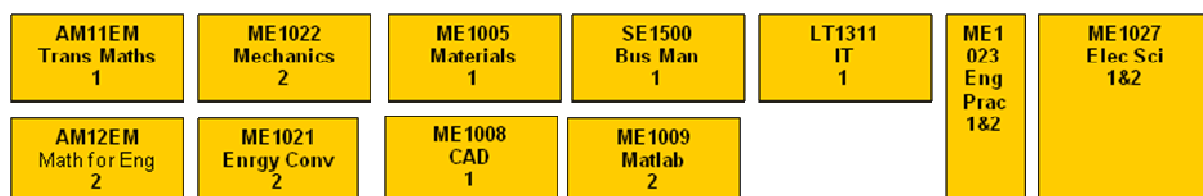


Figure 1: Pre-existing year 1 mechanical engineering programmes

Not only was this was inefficient and burdensome from an academic and student perspective but the combination of modularisation and high work-load for the undergraduates predisposed a strategic learning approach in the majority of students, with an inherent

compartmentalisation of knowledge. Dawes asserts that such compartmentalisation impairs learning as it can prevent the learner from anchoring new knowledge in the context of what they know and at worst can instil a block to the formation of new concepts [5]; i.e. "I'm not very good at thermodynamics". This also led to an apparent inability of many students to adopt a system level approach to design and analysis and consider aspects of several specialisations in a single endeavour. In a survey of engineering professionals Adams *et al* acknowledged the importance of time for reflection on past experience [6]. With such a heavy workload, and a disjointed modular system, there was neither opportunity nor a structure in place to encourage students to reflect on their learning strengths, weaknesses and experiences, or the wider relevance of their acquired knowledge.

A further concern was there was limited opportunity for the students to gain or demonstrate creativity, problem solving or practical skills. The UK Engineering Council's Quality Assurance benchmark statements asserts "the creative way of approaching all engineering challenges is being seen increasingly as a 'way of thinking' which is generic across all disciplines" [3] indicating the fundamental importance of both problem solving and creativity for all sectors of engineering. It was observed that for students working at Level 5 and 6, progress within individual and group project work was consistently frustrated by procrastination, with the majority reluctant to make decisions for fear of failure. This lack of confidence was again identified as being in part a consequence of over-assessment; with no clear 'right answer' the students would consistently defer to academic or technical guidance in order to ensure success. It was also a result of poorly developed problem solving skills, with few opportunities within the analytically biased programme for the students to make valuable mistakes from which they could learn from and reflect upon without the penalty of jeopardising their degree classification. Instilling a cautious attitude to problem solving and decision making is viewed negatively in industry, evidenced again by Adams' survey [6] that confidence and willingness to take risks were essential elements of practical problem solving.

Lastly was the issue of life-long learning. Discussions with several academics on the programme revealed several instances where BEng and MSc graduates were returning to their former academic tutors for guidance and assistance in non-specialist areas after they had started work. Symptomatic perhaps of a lack of confidence, perhaps persistence in the deferral pattern established within their strategic undergraduate learning, or inexperience of self-directed learning. The ability to learn independently is arguably the most important skill of a practitioner of any professional discipline – particularly in fields such as medicine and engineering where technological advances are rapid and as such professional development is a requirement. It was clear that this dependent culture, although inadvertently created was inappropriate for future sustainability of the programme and its graduates.

Desirable criteria for the new programme structure

It may be surmised that although the programmes in MED were strong in the development of analytical skills and practical skills a misalignment had developed between the teaching and learning practices employed and those required to induce the creative, team-working, problem-solving and independent learning skills required in the work-place with a knowledge and understanding of wider business and engineering issues.

In order to improve alignment the programme would need to facilitate increased confidence and experience in solving problems creatively and taking solutions through from concept to reality, drawing on knowledge from various sources and facets of underpinning science, and for independent knowledge creation. To further improve alignment with industry the course materials and activities were also needed to encourage a holistic approach to problem solving which accounted for cost, value and social responsibilities. Finally the activities must provide opportunity for and encourage students to make mistakes and reflect on their

learning, their actions and the consequences, without jeopardising their academic success through inappropriate or excessive assessment.

Problem Based Learning

Modern engineers are required to have specialist technical knowledge as well as interpersonal communication skills, effective team, project and self management methods and techniques, and awareness of social and ethical concepts and responsibilities. Hasna describes the challenge facing the modern engineer well as “whilst trying to incorporate more human skills into their knowledge base and professional practice, today’s engineers must also cope with continual technological and organisational change in the workplace” [2].

The principal themes which resound under the consideration of the new programme structure were those of student-centred problem solving and creativity, encouraging independent learning, the flexible application of multi-disciplinary underlying science, with capacity for reflection and within a structure which aligns academic activities to those of professional practise.

PBL has been used successfully for medical professionals since its inception for the training of physicians at McMaster University (Ontario, Canada) in 1969 and is believed to contribute to a student’s motivation by encouraging active intellectual processes at the higher cognitive levels, enhancing the retention, transfer and modification of information to meet individual student needs [7]. This suggests that implementation of PBL should not have a negative effect on declarative knowledge, but offers significant enhancement through its conversion to functioning knowledge.

Savin-Baden advocates PBL as having largely unrealised potential, offering opportunities in providing skills for lifelong learning, to develop key skills, independence in enquiry and the confidence and ability to contest and debate [8]. He goes on to evidence experiences of PBL practitioners with reference to the capability for managing diversity in terms of facilitator and learner, a promising sign for a course which provides for both analytical engineering students and less analytically focussed designers.

It was clear that through the implementation of such a structure a number of the issues identified in the programme and its participants would be addressed, and through adopting a system or organisational level implementation would facilitate better alignment to student-centred learning. Kolmos *et al* are clear to indicate, however, that in order to ensure cohesion across such a level of implementation requires a clear strategic vision across the organisation [9]. The structure, clear vision and vocational alignment made CDIO an attractive strategy for MED to achieve its aims.

IMPLEMENTING A FUNDAMENTAL CHANGE IN PEDAGOGY

Phase 1 – Establishing the CDIO Modules and Culture at Level 4

Aspects of problem-based learning had been employed previously within the programmes, but only on a small and isolated scale with little interaction with other modules. Most notably the role of the academic had remained constant. The adoption of a new programme-wide delivery structure required academics to re-assess their pedagogical practice in order to align with the ethos of problem-based learning: to alter their academic role to one of being a facilitator as opposed to a deliverer of taught material. Importantly this consistent position was required to be adopted throughout the faculty in order to ensure success. This was seen as being the most important and fundamental change which was required. To address this sessions on best practice were arranged, and other members of staff were encouraged to attend and experience CDIO sessions in order to observe and discuss any concerns.

The restructured programme structure takes the form as shown in Figure 2. This induced a significant amount of work in the planning and writing of new course materials for what constituted 50% of Level 4 undergraduate study. Beyond this further effort was required in preparing Quality Assurance Audit (QAA) and professional accreditation documentation, acquiring finances, resources and financially planning for the next phases of implementation. As such, a conscious pragmatic decision was made to minimise impact on the content and sequencing of the material within the underpinning science modules until the CDIO modules had been established. Accepting an interim period of disjoint between declarative and functioning knowledge building activities until such a time as the appropriate oversight and academic efforts could be applied.

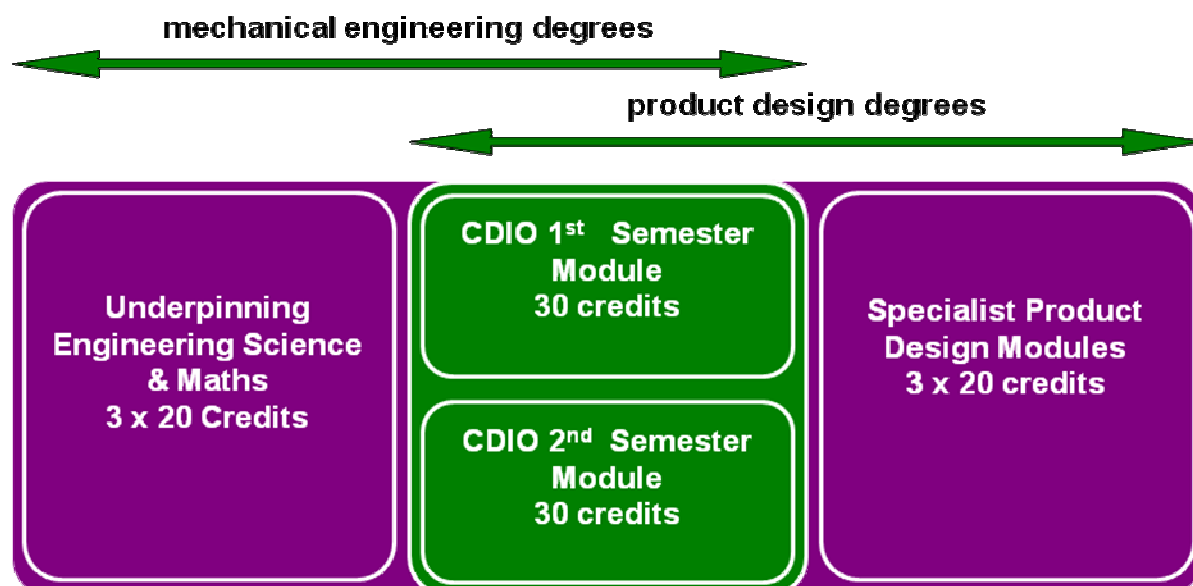


Figure 2: Revised design and engineering programme structure (year 1)

Phase 2 – Progressing the CDIO Modules and Culture at Level 5

The second phase will be embarked upon in October 2011, extending the good practices and refining the format for the uninterrupted continuation of the current CDIO undergraduates into their studies at Level 5 and for the next intake of Level 4 students.

Phase 3 – Aligning Engineering Science Modules with CDIO modules

The final phase of introduction is planned for October 2012 when the sequencing of the underpinning science modules will be altered to better facilitate application and reinforcement of these concepts within the CDIO modules at both Levels 4 and 5. This phase will also incorporate an appraisal of the Level 6 BEng and BSc programmes, and Level 7 MEng and MSc courses, identifying where improvements and efficiency savings can be gained from the adoption of universally adopting CDIO.

IMPLEMENTATION OF PHASE 1

Structuring Sessions

Active learning approaches to contact sessions had been used with success previously within MED, but usually these were limited to aspects of design or manufacture, or centralised timetabling constraints had resulted in these activities being over a protracted

period of short contact sessions significantly limiting progress opportunities and permitting only a single Design-Build-Test iteration per semester.

Opportunities were explored for incorporating intensive multi-day CDIO project sessions at the start or end of each semester, however it was discounted over concerns of student perception of the material as being additional to and separate from the conventional programme material. The large module sessions were instead focussed on whole day (8 hour) intensive sessions occurring every week of the normal semester. In this way a perception of CDIO being at the core of the degree programmes could be reinforced and the declarative knowledge from other modules could be reinforced or functionalised within a much shorter time period of their introduction in other modules.

There were concerns that the use of whole day learning sessions was inefficient, with the risk of students becoming more apathetic, less responsive and lethargic beyond a half day session. Attempts were made to divide the session into 2 separate half day sessions within each week, however this significantly constrained timetabling during Phase 1 of introduction, where academics were still required to support the conventional programmes at Levels 5 to 7. Instead this led to the consideration of methods for maintaining student engagement.

Sessions were structured to create a high-productivity atmosphere, through the use of time-sensitive activities based around what Masek describes as subject-centric 'trigger' problems interspersed with time-limited mini-lectures that are aligned to the contents and objectives of that period of the session [10]. Continual monitoring of the reception of the material, understanding of concepts and canvassing of opinion from the students was administered through the implementation of personal response systems (TurningPoint™, Reivo Ltd, Twyford, UK). The sessions were further structured to follow the phases of the CDIO cycle, with full completion of the cycle within each session, or across 2-3 sessions in cases of larger and more complex activities. In this way more sedentary theoretical and analytical phases were tackled earlier in the morning session and a heavy focus on more energetic and practical work in the afternoon session, closing out with a reflective wrap-up period.

Session Staffing - Team Teaching

In order to maintain a safe working student-staff ratio of 20:1 sessions are manned by a minimum of 5 supervisory staff. Sessions are led by a minimum of 2 academics, one of whom is responsible for primary material delivery and timing of the sessions and the latter being responsible for supplementary material and monitoring student engagement. The remainder was made up through technical support staff and post-graduate demonstrators.

The role of secondary academic has proven to be an important one, alleviated from the responsibility of pacing the session the secondary academic is better positioned to observe body language and observe which concepts are not being followed or understood, as well as interject when the lead has omitted or poorly-explained any material with supporting explanation or examples.

When the session shifts into a period of activity having multiple academics can better service a large number of groups through addressing questions and facilitate academic attention to be paid to groups which require it without significantly reducing time available for others.

Fundamentally from an academic perspective the principal advantage of the team taught paradigm was the collaborative planning of sessions and activities provides a free exchange of ideas, enables potential pit-falls or obstacles to be identified prior to implementation, and also allows the academic team to adapt to staffing issues at short notice.

OBSERVATIONS, REFLECTIONS & INTERIM EVALUATION

At the time of writing MED's CDIO module coordinators had successfully completed the first implementation of the first CDIO module with a mixed cohort of design and engineering students at Level 4 and were in the process of closing out the second module.

Staff Reflections

The largest and most fundamentally important observation made has been in the attitudes of the students taking part in CDIO as observed by academics and technical staff. The students are generally more enthusiastic and pro-active when it comes to participation within the CDIO modules, with a clear evidence of thought, planning, resourcefulness and enthusiasm being brought to every session. There is demonstration of a perceived ownership of the learning environment with high levels of attendance to voluntary self-study sessions in the laboratory and other non-teaching spaces. Perhaps most surprisingly is an attitude change in the students within the more conventional didactic declarative knowledge modules which support the active learning modules. Like-for-like comparison with students of previous years showed that those learning through the CDIO programmes were keener to participate in class discussions, and there is a notably higher incidence and interest in volunteering answers and suggestions to in-class questions.

Academics introduced the new CDIO based programme as being a new venture for Aston, and continually reinforced the experimental nature of the programme and acknowledged the importance of student opinion. The students appeared to react strongly and positively to this, offering opinion and ideas in a predominantly supportive sense.

Generally staff attitude was positive with a large number of academics keen to see and take part in the learning, and attempts were made to be inclusive where possible. However there is still more work to be done in this area as some are reluctant to be involved and in a notable exception two academics who had been asked to lead CDIO sessions used the opportunity to run traditional laboratory sessions and scheduled additional didactic lectures to support assessment. This refusal of the academics to engage with the new learning paradigm proved interruptive with a significant portion of students continuing this work through into later CDIO sessions and led to a temporary collapse of the established working and learning patterns.

At the opposite extreme there were instances where some academics were keen to engage with the process and join sessions as led by other academics. Before each session there would be a briefing session where all academics and technical staff were issued with details of the session and its timings, appraised of the activities, any rules of engagement or other specific session requirements. It was found that when asked questions relating to the activities the additional academics would often give conflicting or inconsistent information as a result of not attending the briefing sessions. In some cases this was seen to cause disquiet amongst the students and create a perception of disorganisation or inequity. This could have been tackled through general release of detailed session notes to the students but this was judged to risk creativity and it was considered desirable that students would be encouraged and practised at enquiring for further information, establishing limits and pushing boundaries. This pattern of questioning practice had clearly been established within the first 3 weeks of semester 1, with the delay between students embarking upon an activity and their posing of considered questions notably diminished.

Significant effort was required in the generation of sufficient course material to fill each session whilst maintaining an appropriate balance of delivery to activity and maintaining alignment with the module learning outcomes. It was found here that the collaborative composition of the schedule for the session between the lead and secondary academic was

extremely beneficial for providing fresh ideas, experience and perspectives as well as sharing material preparation, resource collation and consolidation or 'kitting' of activity equipment. Acquisition of any non-standard laboratory equipment or large quantities of supplies (i.e. eggs, golf balls, wind turbine components) was often hampered by the university purchasing system with frequent reliance upon informal mechanisms (individual purchase and later reimbursement). This added the unforeseen benefit of clearer visibility of project costs and in cases of severe resource limitations considerable feats in creative problem solving.

Logistically pacing the learning and activities for an 8 hour session proved taxing for the majority of academics that engaged in the process, with many sessions over-running and leading to sacrifice of the crucial reflective wrap-up period at the end. With more practice of preparing the sessions it became clear that by maintaining a strict time regime for activities had a dual benefit of both improving timing but also in catalysing engagement and higher levels of activity. Naturally this works best if the students have grasped the concepts and the material prior to the activity – but the rapid diagnosis, redelivery and reinforcement can limit any slippage.

Groups had been allocated randomly, which inevitably resulted in some groups being from a single discipline (i.e. purely from design programmes, or engineering programmes) as opposed to a clear mixture. At this level there was not a stark difference in the performance of these groups from those of more mixed teams. However it was globally observed that tasks involving mental arithmetic or algebraic manipulation there were consistent difficulties in most teams. This remains an area of concern and one which will be the focus of development in subsequent implementations.

Assessment and feedback

The experimental nature of the module, offering a significant departure from conventional teaching methods facilitated a more experimental approach to assessment and feedback methods. Each session bore an aspect which was assessed independently through the evaluation of design-build-test success, but there were also longitudinal assessments in the form of personal response system activity for individual and peer assessment, and in the form of a reflective journal or 'blog' which accounted for the student's learning and activity throughout the session.

Personal response systems

Turningpoint™ PRS (Personal Response System) handsets were assigned to each individual within the class, and each individual was assigned to a group. This permitted the use of the data from the PRS systems to monitor individual and group attendance, provide individual and group formative assessment and individual and peer summative assessment. Furthermore feedback could be provided instantly by the academics in the session thus better enabling feed-forward for later use in the session and beyond.

Implementation of PRS enabled the efficient use of concept questioning techniques to establish comprehension of freshly introduced concepts and the reinforcement of previous material with the large group.

Individual and group reflective blogs

At the end of each CDIO sessions students were encouraged to reflect on their experience of the day, and to relate their experience to the learning outcomes listed in the module specification and record their thoughts and experiences on an online blog within the blackboard VLE. Mid-way through the teaching period students were then asked to read

through their blogs and identify and provide supporting evidence and incidences of their demonstration of specific learning outcomes within their blogs. This required formal reflection on both the quality of their learning and the quality of their blog as a record of their work.

The blog was also extended to the academics coordinating each session. A teaching blog with academic-only access enabled communication of both administrative data (such as PRS reports and attendance records for tier-4 and DTUs (Defence Technical Undergraduate Scheme) student monitoring), advisory notes or recommendations for other academics pertaining to the teaching facilities, group problems and observation of students that are struggling. This document also served as evidence for Quality Assurance Audit (QAA) purposes in terms of module reflection reports and strategic recommendations for programme and school boards.

Peer reflection and feedback

A particular innovation was made in the assessment of a typically difficult area of group-project work which is the apportioning of marks for team work. Each individual was asked to appraise themselves and their team-colleagues against a series of characteristic statements. The statements were designed to be equally positive and negative so as to avoid overt assaults on any individuals and reflect a previous exercise where they were asked to reflect on their team working and management strategies. The results were then collated for all individuals and returned, providing each individual an honest reflection of any discrepancy between how they saw themselves and how their group perceived them to be. This exercise indicated that in the majority of cases individuals were accurate and honest about their levels of commitment to the course and their support of other members in their group, and in some cases group members viewed the contributions of their colleagues more positively than they did themselves.

EFFICIENCIES

A number of efficiency gains have been identified as a result of implementing the revised CDIO-based programme at Aston, and these may be categorised as marking and assessment and space utilisation. These figures have all been put into the context of the 2 years prior to implementation.

Table 1 shows a breakdown of the number of modules on the two programme streams (engineering science based and design based) and indicate the number of students and the number of individual units of assessment requiring academic attention. Assuming each module has on average 3 units of assessment it is clear to see that the number of formal assignments which must be completed by students are reduced by 54.6 % under the new architecture. Meanwhile formative and summative data collection frequency has been increased through the administration of in-session PRS tests and regular group discussion with academics.

Table 1

The number of units of assessment has been significantly reduced through CDIO implementation

Programme Stream	2008-9			2009-10			2010-11		
	number of students	programme module count	Total assignments	number of students	programme module count	Total assignments	number of students	programme module count	Total assignments
Engineering	67	11	2211	59	11	1947	74	6	1332
Design	50	11	1650	31	11	1023	28	5	420
Total	117		3861	90		2970	102		1752

The first CDIO module (ME1501) replaced 3 pre-existing 10 credit modules, and their space requirements are compared in

Table 2, showing that the initial investment of £20,000 in upgrading an under-utilised engineering laboratory into a dedicated CDIO workspace has resulted in a 37% reduction in learning space requirement within just the first semester.

Table 2

Significant reduction in space utilisation through employing a dedicated multi-use learning space/laboratory

	Equivalent 3 x 10 credit modules	New CDIO module
	2 x 44 hours in lecture theatre 1 x 22 hours in computer laboratory 10 x 3 hours in engineering laboratory	11 x 8 hours in engineering laboratory
Total	140 timetabled hours	88 timetabled hours

EARLY INDICATIONS OF OUTCOMES

Despite the efficiency savings and the significant overhaul of the level 4 undergraduate programmes the interim results are favourable.

Table 3 shows a summary of the module board results of the 2 years prior to implementation (based on modules which have been replaced by the CDIO module) and this year (2010-11). The results indicate that despite the significant changes there has been a maintenance of consistent academic challenge in both Engineering and Design based streams with average grades remaining consistent between years.

Furthermore, if we assume that the instances where students have scored zero in a module (classed as a non-attempt) it may be seen that reducing the number of small low credit bearing modules and the incorporation of true continuous assessment, monitoring and feedback has eliminated this in the new structure. The number of individual module fails from the 3 years also shows that despite the maintained academic challenge the instances of failure have decreased, but with the significantly higher credit bearing of the CDIO module the number of 10 credit module equivalents being failed has increased as a result of the 30 credit weighting of the CDIO modules. This has effectively reduced the opportunity for less committed students to progress through strategically focussing on their strengths and relying upon examination board processes.

Table 3

Summary of module board results from pre-implementation with those of 2010-11

Programme Stream	2008-9		2009-10		2010-11	
	Pass rate (%)	mean grade	Pass rate (%)	mean grade	Pass rate (%)	mean grade
Engineering	97.0	61.2	93.2	61.5	93.2	60.6
Design	83.4	52.6	95.3	60.5	82.8	54.8

Engineering & Design

number of students	117	90	102
number of non-attempts	11	16	0
Individual module fails	35	25	13
10 credit module equivalents failed	35	25	39

CONCLUSIONS

Aston's experience of CDIO has been extremely positive, with the implementation providing a catalyst for experimentation with new learning and teaching paradigms and techniques, as well as in establishing new cultures and modes of working within the faculty. The translation of the engineering and design programmes away from didactic teaching and towards student centred active and problem based learning is already beginning to indicate some of the expected outcomes of a PBL environment. Students are demonstrably taking higher responsibility for their learning and benefitting from higher motivation and engagement. Academic standards are being maintained consistent with levels prior to implementation at the same time as considerable efficiency gains are being made in terms of formal assessment loading and space utilisation.

Despite benefitting from a critical mass of CDIO practitioners there is still significant progress to be made in terms of establishing a PBL culture at Aston. This is, after all, experiential learning and a cultural change is required in academics and technical staff as well as students. Further efforts are required to induce more widespread adoption of the practices and inclusion of a larger proportion of the staff through education to eliminate misconceptions around what CDIO represents ("I already do project work"), or concerns over potential for additional work in a burdensome climate.

Academics whom have embraced the culture have found it to be an exciting and refreshing approach to engineering education, although the process of implementation has been intensive. It is demanding in terms of financial planning and coordination. Although not significantly more demanding than composing any new taught programme material it does require a higher degree of coordination and cooperation between academics to support the team teaching paradigm; Learning outcomes, material for delivery, resources for reinforcing activities require identification, development, procurement and compilation well in advance. Furthermore new approaches to collaborative material preparation and delivery is breaking down conventional feudal barriers of module ownership and demonstrating key benefits and encouraging experimentation with learning and assessment tools and techniques.

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EXPERIENCE OF FIRST YEAR CDIO IMPLEMENTATION AT VNU-HCM

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ABSTRACT

Along with the development of economy and society, Vietnam is facing a challenge of training a skilled labor force. This requires improving the education system, especially higher education, to meet society needs. As a flagship and the largest university system in Vietnam, the Vietnam National University-Ho Chi Minh City (VNU-HCM) System has spearheaded many initiatives to improve the quality of education in Vietnam. A key effort in these initiatives is VNU-HCM's leadership in adopting and adapting CDIO principles to build a model framework for widespread implementation of CDIO in Vietnam. In this paper, we present the first year experience of implementing CDIO at VNU-HCM from the point of view of a system of universities and the achievements that we have accomplished. In particular, we discuss: (i) the lessons learned and the challenges in promoting cultural changes, in treating human as a the most valuable asset in bringing about changes, and in sharing and disseminating our work within our university system and engaging peer institutions in Vietnam; (ii) the policy supports needed for organizational changes at system, university, and department levels; and (iii) our evolution of the development of a model framework for widespread implementation in Vietnam and initial results which suggest that the model framework has the potential for accelerating the efforts, improve the efficiency and increasing the likelihood of success for universities that are participating in the adoption of CDIO.

KEYWORDS

Vietnam CDIO, First Year, Implementation Model Framework, VNU-HCM

I. INTRODUCTION

Along with the development of economy and society, Vietnam is facing a challenge of training a skilled labor force. This requires improving the education system, especially higher education, to meet society needs. As one of the flagship universities in Vietnam, the Vietnam National University-Ho Chi Minh City (VNU-HCM) System has spearheaded many initiatives aiming to improve the quality of higher education in Vietnam. A key effort in these initiatives is VNU-HCM's leadership in adopting and adapting CDIO principles to build a model framework to help accelerate national efforts in curriculum reform through widespread implementation of CDIO in Vietnam.

VNU-HCM started the preparation for the implementation of CDIO in 2008 [1]. Along with the leadership from the highest level, requisite supports expanding have accomplished during the preparation, since January 2010, VNU-HCM officially pilot implementation of CDIO at two departments of member universities: Department of Information Technology, University of Science and Department of Mechanical Engineering, University of Technology [2]. The pilot implementation has two main goals [1]: (i) adapt CDIO principles to systematically reform the

curriculum of our strategic university departments and to provide students with the knowledge, skills, and attitudes desired by relevant stakeholders; (ii) use the pilot implementation of CDIO at our strategic university departments as a means to develop generalized solutions that can be exported and replicated at universities within VNU-HCM System and at other universities throughout Vietnam. In this paper, we present the first year experience of implementing CDIO at VNU-HCM from the point of view of a system of universities and the achievements that we have accomplished.

II. LESSONS LEARNED AND THE CHALLENGES IN PROMOTING CULTURAL CHANGES

In 2010, our strategic departments began and have succeeded in applying the CDIO Syllabus and Standards as a guidelines for curriculum design and development in order to build the learning outcome and curricula for the Information Technology and Manufacturing Engineering Programs [3, 4]. What we have done is only the very first achievement but it results from a process of cultural and organizational change to improve the curriculum, teaching and learning methods and to provide the students with knowledge, skills and attitude meeting the stakeholders' demands.

The results are obtained due to the considerable contribution of many relevant parts of VNU-HCM, especially the great efforts of the managing board at the system level in applying and developing the solutions for change process management based on successful factors of CDIO [5] in order to create the impacts which promote the implementation of CDIO at VNU-HCM and in Vietnam.

1. Creating the motivations for moving off assumptions so as to implement CDIO

Before implementing CDIO, the design of a new curriculum or development of an existing curriculum in almost all universities of Vietnam are often conducted by key faculty members and there is almost never any participation or ideas from the alumni or other stakeholders. The interaction between this key group and other faculty members in departments is very limited. The faculty members are not provided with any official instruction for curriculum design and development in order to provide students with knowledge, skills and attitude to meet the needs of stakeholders. We have determined that creating the motivations for moving off assumptions plays an important role to implement CDIO.

In the preparatory stage for CDIO implementation, most of the relevant participants at our member universities were aware of the necessity and importance of CDIO; however, there were no official commitment from the member universities at that time. In that context, leaders of VNU-HCM have applied the rights of making decisions on education reforms to assign two departments and decide to support them in planning the project and funding for the initial implementation [1]. However, in the stage of implementation, we still have difficulties in helping all of the faculty members move off assumptions and try applying new things, such as CDIO Initiative. Our solutions to overcome these difficulties are having direct impacts on relevant participants in CDIO implementation: (i) through academic activities, we frequently arouse and confirm the important roles, great responsibilities of managers, leaders and mainly the faculty members in providing a qualified curriculum—no one but them can perform these roles; (ii) we have invited international CDIO experts to consult with faculty members and staff about experiences in improving the curriculum; (iii) we asked the member universities to send the faculty members to attend the annual regional CDIO conferences with the partial funding from VNU-HCM in order to have stronger impact on their awareness. This method is confirmed to be the most effective way to persuade the faculty members.

2. Promoting “Envolment and Ownership”

The involvement and ownership of CDIO of most members at universities and departments are still limited. We have promoted this involvement and ownership by assigning them the rights and responsibilities for using the budget from VNU-HCM; directing to establish CDIO Implementation teams at university level including the Vice-Rector (Academic), head of the academic affairs office, head of the quality assurance office, the department dean/vice dean (Academic) and several core faculty members who directly implement CDIO at subject levels. We have successfully defended the CDIO Project of VNU-HCM to the relevant ministries and got the approval for a separate budget from the government to implement CDIO (at system level and universities level). In addition, we have been continuously seeking more funding for the implementation for 7 years of the Project.

At the system level, we have expanded the involvement and ownership of relevant parts in order to fully support the implementation. Not only the Academic Affairs Department but also other functional administrative departments at VNU-HCM are responsible for the implementation of CDIO. This is confirmed by our President by assigning the two Vice Presidents and other relevant functional administrative departments to involve in the implementation. For instance, the Planning and Finance Department has actively instructed the Academic Affairs Department and the pilot departments to complete the annual financial planning for CDIO work as well as has balanced the financial resources to support more for the implementation in addition to the government budget for the Project. The Department of External Relations has successfully registered the membership of Worldwide CDIO Initiative and effectively coordinated the international cooperation to implement CDIO. In 2012, we hope to involve the Quality Assurance Center in support the evaluation of the CDIO programs.

We have also invited international experts to be involved in CDIO implementation at VNU-HCM. In addition to the participation of Dr. Ho Tan Nhut- California State University, Northridge, U.S.A, from 2008; in 2010, VNU-HCM has invited Dr. Peter J. Gray, Director of Academic Assessment - Faculty Enhancement Center, United States Naval Academy to take part in evaluating the curriculum design and development under CDIO model framework at 2 pilot departments. The participation of international experts helps us have more external human resources; on the other hand, the participation of experts with high experience of Vietnam higher education and CDIO implementation has a great impact on persuading and attracting the participation of faculty members. We will try to draw much more attention from international experts.

3. Sharing and disseminating our work within our university system and engaging peer institutions in Vietnam

To help accelerate the nation’s curriculum effort and facilitate widespread implementation of CDIO, we have been broadly disseminating the implementation materials and results. We have translated the CDIO book into Vietnamese and gave it for free to universities attending the workshops that MOET organized throughout the country to promote CDIO in January 2010 [1]. This book has been reprinted in November 2010.

We host a CDIO website that makes available in Vietnamese the CDIO Syllabus, Standards, lessons learned and solutions to common implementation problems. This website is also used to support CDIO activities at VNU-HCM and disseminate the materials developed by the implementation of our model framework. Because CDIO has been implemented at two departments at two different universities within the VNU-HCM system, the CDIO website will help to manage data and information, to share materials and resources. Through the website forums, our members can discuss and share and coordinate activities to reduce cost. This website is an open and accessible channel for VNU-HCM to promote CDIO activities with

collaborators all over the world and to enable us to learn and share ideas, results and achievements and get feedback on our work.

Annually, we have hosted and participated in national and international conferences, workshops to share and learn the CDIO implementation experience. In May 2010, we invited CDIO expert to train our faculty in building learning outcome and integrated curriculum applying to the pilot departments of VNU-HCM. We also took part in the 6th CDIO International Conference in Canada in June 2010. In the conference, VNU-HCM successfully defended the application and was officially approved to become the 56th member of the Worldwide CDIO Initiative. We also presented a report on “Development of a Model Framework for CDIO Implementation in Vietnam” receiving good comments for the CDIO implementation approach at VNU-HCM. We also met international CDIO experts and had their consultants in CDIO implementation in Vietnam. The membership of Worldwide CDIO Initiative supports VNU-HCM to establish the relations with other members of the Initiative as well as to take advantage of experience and materials supplied by CDIO Initiative.

To share experience in designing learning outcomes and integrated curriculum based on CDIO approach in the first year of implementation, VNU-HCM organized the workshop on “Designing learning outcomes and integrated curriculum” on 13-14/12/2010 with the participation of many Vietnam universities, several regional universities such as Tsinghua University (China), Singapore Polytechnic (Singapore), Taylor’s University (Malaysia) as well as experts from Worldwide CDIO Initiative: Dr. Ho Tan Nhut from California State University, Northridge and Dr. Peter Gray from United States Naval Academy. This workshop is also an opportunity to evaluate the implement of CDIO model in VNU-HCM during a year and to share experiences with domestic and international colleagues. In the workshop, the participants presented their experience in the process of applying CDIO approach in building the learning outcomes and curriculum. In addition, the delegates discussed the potential cooperation among domestic and regional universities in CDIO implementation. The workshop promote the awareness on CDIO model as an approach to improve the curriculum, teaching and learning methods, work spaces as well as the quality of higher education graduates.

III. THE POLICY SUPPORTS NEEDED FOR ORGANIZATIONAL CHANGES AT SYSTEM, UNIVERSITY, AND DEPARTMENT LEVELS

VNU-HCM understands the resources are important factors in maintaining the stability of CDIO implementation at the pilot departments. Therefore, VNU-HCM has developed policies and sought the financial resources for CDIO implementation. We had the following methods to find funding from various resources: (i) We submit proposal for supplemental funding from the government budget: this resource is not large because the CDIO Project has not been included in the list of national key programs. We have made great effort for this task, which resulted in a supplemental funding from the government in 2011 for the project; (ii) VNU-HCM encouraged the financial contribution from member universities of the pilot departments: In 2010, the University of Science added new fund to build several new courses for D-I skills (Design-Implementation) for the Information Technology Programs; (iii) A regulation concerning finance of CDIO implementation was issued as a sustainable solution for the fiscal year 2010 and the planning of the fiscal year 2011. VNU-HCM gives financial support to CDIO activities at VNU-HCM level and member universities level. At department level, funding are used to pay faculty members for their time and efforts in involving in research, survey, program benchmark, training and teaching.

Until the fiscal year 2011, we have raised funds from various resources and member universities have added necessary funds for the key activities in CDIO implementation. University of Technology has spent considerable funds to build new workspace for practicing D-I skills in

Manufacturing Engineering Programs. University of Science has allocated the plan for the practice rooms of C-D-I-O skills in Information Technology Programs.

To ensure the initiative and responsibility spirit in using effectively funding resources, VNU-HCM has required the departments to have the implementation planning and to defend the budget planning. VNU-HCM also holds the annual formative and summative evaluation of CDIO implementation at department level.

One of the difficulties in implementing CDIO is the working time of faculty members, especially the key people of the implementation. In addition to be involved in CDIO implementation, they still have to ensure their teaching and research in their major. The departments and we (VNU-HCM) had quite many discussions about this matter and the solutions now are: (i) The working load involved in CDIO Project is considered the same as one in teaching; their research paper, articles about their CDIO implementation are considered the same as those in specialized fields; (ii) In addition to the key force, namely CDIO implementation Team, the departments have build many specialized groups with wider participation, also including academic staff from other departments. These groups have been operating simultaneously to support one another. This initiative is rooted the Department of Information Technology - University of Science and have undertook since early 2010. The Department of Mechanical Engineering has also applied this operation; (iii) The establishment of a center of excellence for CDIO implementation is a long-term solution. This center will provide sample procedures, models for teaching under the CDIO framework as well as training course for faculty members. This is supposed to solve the current problem of faculty members' working overload.

At the time being, we have a Center for Educational Excellent (CEE) at University of Science that provides faculty members and students with effective teaching and learning methods. With its participation in CDIO implementation, we have taken advantage of the experiences from the Center in training teaching methods for faculty members. In the initial phase, we have also invited experts from the Worldwide CDIO Initiative to support the faculty training.

IV. OUR EVOLUTION OF THE DEVELOPMENT OF A MODEL FRAMEWORK FOR WIDESPREAD IMPLEMENTATION IN VIETNAM AND INITIAL RESULTS

1. Evolution of the development of a model framework for widespread implementation in Vietnam

The implementation of CDIO not only have raised the academics staff's awareness of designing and developing of curriculum but also have promoted the innovation in teaching and learning methods.

To meet increasing demand for quality training, the implementation of this model is considered one of the most effective method to standardize the curriculum design and development. The lessons of VNU-HCM in developing curriculum under the new approach are scientific evidence and practical experience for other training institutions in the country. After the initial preparing and implementing years, the original model has been continuously customized and developed. One of the most important factors is to create the consensus of the stakeholders in the process of implementing CDIO.

The solution to a sustainable consensus in the extension of CDIO implementation is to institutionalize the implementation. In fact, the consensus among the leaders of VNU-HCM is available. Most faculty members were ready for the implementation as they recognize faculty members are the very first beneficiary of this education reform activities. However, the faculty members still need the department leaders' official commitment which leads to a proposal to the university leaders for specific policy and support in CDIO implementation. The solution is to

utilize the high consensus to institutionalize the extension of CDIO implementation into the mid-term development planning of VNU-HCM from 2011 to 2015.

Another way to increase consensus in solving problems during the implementation and use of resources is to create an alliance of departments that have common fields in implementation. Currently, the alliance includes the Department of Mechanical Engineering - University of Technology and the Department of Information Technology - University of Science. The CDIO pilot programs help improve the curriculum of the two departments and also play a key role to extend to the other departments. The collaboration between the two departments enables the mutual support and resources sharing. In the process of simultaneously implementing CDIO, the two departments found different solutions to common problems, conducted difference approaches and then compared the results. Each year, VNU-HCM intends to have several departments involved in CDIO implementation alliance; that new departments can take advantage of the results obtained from the previous departments. The experience sharing and mutual support will promote the implementation of CDIO at VNU-HCM, reduce cost and increase the success possibility.

In addition, in the process of implementing CDIO, we draw participation from not only faculty members and students but also industries and alumni. To developed countries, the participation of the enterprises and alumni in the process of improving the curriculum is mandatory. However, this trend is new in Vietnam. Therefore, attracting the enterprises and alumni to participate in the process of developing the curriculum at some pilot departments is an innovation. It requires us to focus specially on monitoring and developing these relationships. In order to accomplish this, we usually invite enterprise leaders to the information sessions about CDIO implementation and what are being done. Initially, these enterprises were not acquainted but they gradually understood their roles in university's training process. When designing learning outcomes and curriculum, we always collect feedback from the enterprises. It helps making the curriculum stay updated and meet the requirements of the enterprises. Leaders of the enterprise which have employed many graduates from the department are invited to the council of the department. In that way, these enterprises accompany us during the whole training process. When the enterprises also are the co-owner of the training process, they will be more responsible for training the students to serve their specific enterprises. We also can receive donations from the enterprises to help solving the financial problem.

To the alumni, we use a variety of electronic communication methods to convey information and collect feedback. The feedback of the alumni who are currently working will help us identify the mistakes in the training process. Annually, we hold alumni meeting to update their current work. We have contact persons for each generation. Many alumni who become key leader in these enterprises contributes more and more to our training process.

Hence, the roles of the enterprises and alumni, in addition to the faculty member and students, are extremely important in the process of curriculum designing and developing. Many departments have not paid much attention to these stakeholders before. However, after this experience, other departments is strengthening the relationship with the enterprises and building the data of the alumni. It will be very useful for the initial phase of CDIO implementation and curriculum improvement at the other departments.

Last year, the two pilot departments implemented initial steps in developing learning outcomes and designing curriculum under the CDIO model framework. All the experiences and results of the two departments have been reported to faculty members of other departments in VNU-HCM. Since then, some departments has been aware of the importance of improvement the curriculum to meet the requirements of the enterprises. Although funds have not been granted, these departments have already begun to study CDIO approach to their own departments. This shows

that the implementation at the two pilot departments has positive impact on the other departments in VNU-HCM.

Furthermore, last year we held an international workshop with the participation of many domestic and foreign universities. After the workshops, participating Vietnam universities realized that CDIO could be a reasonable solution to improve the curriculum. They would to receive assistance from VNU-HCM in implementing CDIO model framework. We did support them in planning the implementation plan and also hold introduction and training courses about CDIO for other universities. Currently, there are about ten universities that are planning CDIO implementation. This shows the CDIO model, that we are implementing provide a methodology and solutions that can assist the Vietnam universities in the comprehensive education reform.

This year, we plan to establish a club of all universities that implement CDIO in Vietnam to exchange and share experience. A reference book on CDIO learning outcomes design and curriculum development at VNU-HCM is being editing in order to disseminate information within the club members in the future.

2. Initial Results

In 2010, our pilot departments have successfully designed learning outcomes and programs for the Information Technology and Manufacturing Engineering Programs under CDIO model – an absolutely new approach. The departments adjusted CDIO syllabus to each programs, conducted surveys and group discussions, studied the material, organized workshops to learn about enterprises' demands and how the current curriculum can meet the needs. After that, they modified the curriculum. The process is implemented for the two faculties as following:

Designing learning outcomes and integrated curriculum at the Department of Information Technology

The CDIO implementation team built new learning outcomes based on the existing learning outcomes, curriculum framework, and the CDIO Syllabus. This new learning outcomes is of the 3rd level of details. Learning outcome are adjusted to the Information Technology field. The department decided to split and merge skill groups in order to monitor more clearly. In particular, group 1 still includes basic skills and fundamental knowledge. Professional and development skills are in group 2. Group 3 is a list of rubrics which relate to environment, enterprise, society and personal responsibilities. Group 4 includes teamwork, foreign language skills and personal characteristics. Group 5 and 6 were extracted from section 4 of CDIO Syllabus: conceiving, analyzing, designing and implementing skills are introduced in group 5; verification, validation, operation, maintenance and evaluation skills are introduced in group 6. The new way of group division is more suitable for the Department's curriculum. By this way, besides the skills are gathered, building an IT product is separated from its verification, and operation.

After developing the learning outcomes of the 3rd level of details, the Department conducted a survey with stakeholders in order to evaluate the training as well as stakeholders' expectation. Survey was conducted with 86 lectures, 697 alumni, and more than 30 enterprises.

The results of the survey were analyzed for building learning outcomes of the 4th level of details. Based on that learning outcomes, the Department have built an integrated curriculum. In comparison with old programs, the CDIO programs have several changes: 4 new subjects are added, some existing subjects are adjusted to meet the expected student proficiency. The detailed results of designing learning outcomes and integrated curriculum of Department is analyzed in the other report.

Designing learning outcomes and integrated curriculum at the Department of Mechanical Engineering

The CDIO Implementation teams have discussed and evaluated of the level of detail of the CDIO Syllabus. 97 criteria at the third level of detail was considered quite detailed and therefore was used to conduct surveys. The survey was conducted on 53 faculty members, 124 last year students, 50 alumni and more than 40 representatives from the enterprises.

After determining the expected learning outcomes, the department benchmarked the training program in accordance with ITU and conduct survey on subject input - output through the "Black box". 65 subjects of the Manufacturing Engineering training program was in the survey to the faculty members and the head of the subject. According to the results benchmarked with learning outcomes, the current training programs ensured most of the knowledge, skills; however, it did not meet the expected learning outcomes. Thanks to the "Black box", the department has reset the sequence of subjects. Basically, the new training program was designed from the current subjects, but the programs was restructured to ensure connectivity and support to one another. The personal skills, communication, creation of products, processes and systems are tightly integrated into the curriculum.

V. CONCLUSION

To innovate compressively the curricula, VNU-HCM has developed and implemented a model framework based on the adoption and adaptation of CDIO approach, an Initiative for engineering education reform being adapted by many universities. Not only the initial results improve basically content of the programs, teaching and learning methods, and learning environment for the pilot programs, but also they have successfully convinced the faculty members and staff change from the un-professional working way to an scientific, systematic one as CDIO approach.

Through the implementation of CDIO, we have more practical basis for strengthening and improving the policy for education reform: human resource are the most important one to enable change - innovation in education. Thus, the education reform can succeed only when there are reasonable policy to create motivations toward cultural and organizational change in education system. The lessons learned from VNU-HCM's CDIO implementation are useful scientific basis and practice for other universities across the country. The CDIO implementation pilot model of VNU-HCM will be continuously improved so as can be widely disseminated within VNU-HCM system and to other universities.

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EXTENDED DEGREE PROGRAMME STUDENTS' EXPERIENCES WITH THE SKYSCRAPER ACTIVITY

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ABSTRACT

An activity called “Skyscraper”, developed as part of the CDIO initiative (<http://www.cdio.org>), was implemented with 275 first year students in the Engineering Augmented degree programme (ENGAGE) at the University of Pretoria. ENGAGE is an extended degree programme for students who are not ready to cope with the mainstream programme without support. Implementation of the Skyscraper activity involved logistical challenges as the 275 students were divided into six classes, each of which met for three 50-minute periods in the same week in normal classrooms. All the materials had to be carried from room to room. Within each class, students were divided into groups of about nine people. Students were marked according to six criteria. In a secondary analysis of students’ results each group’s performance was assessed according to 12 criteria. Problems identified included incomplete project plans, failure to identify constraints or produce a thorough design, not building what was designed, poor time management, failure to perform calculations, incorrect budget calculations, careless mistakes, poor presentation of designs and the need to change the design after building. These problems can be attributed to a variety of sources, including inadequate life skills, poor understanding of basic mathematics, inattention to detail, not understanding the importance of creating and following a design and not transferring knowledge from one context to another. Students who planned poorly may have wanted to get on with what they perceive to be the task—building the structure—arising, perhaps, from their experience of figuring out how gadgets work without reference to systematic analysis or written instructions. For ENGAGE students to gain greater benefit from the Skyscraper activity we may need to devise more structure, such as checkpoints, checklists and budget and materials templates, and create the role of quality assurer in each group. On the positive side, nearly all groups functioned well, especially those that were diverse in terms of race and gender.

KEYWORDS

Skyscraper, extended degree students

INTRODUCTION

South Africa became a constitutional democracy with universal franchise in 1994. Prior to that, the national policy of separate development, or “apartheid”, allocated resources differentially according to race and required people of different races to live in separate areas. The highest per capita expenditure was given to Whites, then Indians, then people of mixed race, with the lowest expenditure being allocated to the majority population comprising indigenous Africans. The effects of this policy are still being felt 17 years after the end of apartheid in health, housing, infrastructure and education. Science, technology, engineering and mathematics (STEM) education are a priority for the government [1], as there can be no development without adequate skills in these fields. While improving the quality of education, especially STEM education, needs to begin in primary school, South Africa cannot afford to

wait a generation for the school system to improve before it takes steps to increase the number of STEM professionals produced by universities.

Universities therefore embarked on various academic development initiatives, pioneered by a small number of universities more than 20 years ago. By 2001 most universities had some sort of special programme [2] in science and/or engineering for students from historically disadvantaged backgrounds. These programmes were typically “add-on”, meaning that additional courses and other forms of support were provided that did not count towards the degree. Furthermore, while the programmes were usually exemplary in terms of curricula and teaching methods, they were often taught by junior staff and had little impact on mainstream academics or courses.

A longitudinal study of the cohort of students that entered all South African contact universities in 2000 [3] showed that only 38% had obtained a bachelors degree after five years. (The regulation time is three years for a general bachelors and four years for a professional bachelors degree, such as engineering.) In engineering this figure was 54%, with a large difference in graduation rates for White and African students, 64% and 32%, respectively. It was clear that many students could benefit from academic development and support.

In 2006 the Minister of Education declared that all academic development programmes had to be mainstreamed. That meant incorporating them into credit-bearing, extended degree programmes with a coherent curriculum and opening them up to all races. At the University of Pretoria, a five-year programme in engineering had been in existence since 1994 in which the first two years of coursework had been distributed over three years, with extra tutorials offered in some first-year courses. However, statistics compiled for the 2002 cohort of students in that programme showed that after seven years only 54% of students had graduated. Of the African students only 35% had graduated [4].

A new problem arose in 2009 when the first group of students who wrote the new national school leaving examinations based on a new curriculum performed very poorly in their first year university STEM courses around the country. Anecdotal evidence suggested that these students’ knowledge of basic facts, ability to solve problems and experience with working hard were less than those of previous cohorts of students. A study at the University of the Witwatersrand showed that student performance in mathematically-based courses decreased significantly [5]. Thus in 2009 a new 5-year extended degree programme for engineering was designed, the Engineering Augmented Degree Programme (ENGAGE).

STRUCTURE OF THE EXTENDED DEGREE PROGRAMME

The design of the Engineering Augmented Degree Programme (ENGAGE) was informed by the first author’s experience in developing the Science Foundation Programme at the then University of Natal in the early 1990s [6,7]. In designing that programme, cognisance was taken of Vygotsky’s notion of the need for enculturation (in that case to the university) [8] and to provide “good instruction,” about which Vygotsky (quoted in Wertsch and Stone [9]) says,

“instruction is good only when it proceeds ahead of development, when it awakens and rouses to life those functions that are in the process of maturing or in the zone of proximal development.”

The implication of this statement for an academic development programme is that as students develop the demands of the programme need to increase.

The design features of the ENGAGE programme were articulated as follows:

1. Students should be supported in making the transition from high school to university.
2. Student workload (time students spend working) should be high throughout.
3. The volume of work (amount of content covered) should be low initially and increase over time.
4. Support should be high initially and decrease over time.
5. Students should encounter familiar subjects early in the program, less familiar subjects later on.

These principles are applied in practice in the following ways [10]:

1. All 16-credit (one credit represents 10 hours of notional study) level 100 modules are augmented by an additional 8-credit module.
2. In Year 1 students take a reduced load comprising only level 100 basic sciences modules and additional modules, together with two semesters of the skills-based course Professional Orientation.
3. In Year 2 students take level 100 engineering modules and additional modules plus half of the level 200 mathematics.
4. In Year 3 students take level 200 engineering modules and the rest of the level 200 mathematics. The credit load is only slightly lower than for mainstream students in Year 2.
5. In Years 4 and 5 students join the mainstream for level 300 and 400 modules.

Professional Orientation and the additional modules are developmental in that their focus is on developing a range of cognitive, metacognitive, academic and communication skills as well as conceptual understanding. Table 1 provides a comparison between the ENGAGE curriculum and the mainstream 4-year degree programme.

Table 1
Comparison of the Structure of the ENGAGE and 4-Year BEng Programmes

ENGAGE		4-Year Programme	
YEAR 1	credits	YEAR 1	credits
Mainstream Science (level 100)	64	Mainstream Science and Eng (level 100)	144
Developmental	48		
YEAR 2			
Mainstream (level 100 + one 200)	96	Mainstream (level 200)	144
Developmental	32		
YEAR 3			
Mainstream (level 200)	128	Mainstream (level 300)	144
YEAR 4			
Mainstream (level 300)	144	Mainstream (level 400)	152/160
YEAR 5			
Mainstream (level 400)	152/160		

Since ENGAGE students take no engineering modules in year 1, they have little exposure to engineering except for some of the projects in Professional Orientation and reading *Engineering News*, a weekly South African magazine. It therefore seemed very appropriate to provide them with an opportunity to do the Skyscraper activity that was developed as part of the international CDIO initiative. According to the CDIO website (<http://www.cdio.org>),

“The CDIO™ initiative is an innovative educational framework for producing the next generation of engineers. The framework provides students with an education stressing engineering fundamentals set in the context of Conceiving — Designing — Implementing — Operating real-world systems and products.”

PREPARING TO RUN THE SKYSCRAPER EXERCISE

In the level 100 Physics module students cover Newtonian mechanics, including centre of mass calculations. Since this is the only background knowledge required for the Skyscraper exercise, we decided to do the exercise in the Additional Physics module soon after centre of mass had been covered.

The Skyscraper activity has been developed over time by members of the CDIO initiative. A detailed document, Skyscraper Template, by Dan Frey and Ed Crawley from MIT, can be downloaded from the CDIO website. According to the document, the overall goal of the activity is to, “Allow students to describe, anticipate and plan for some of the realistic factors encountered in a real engineering project through a team activity.” In the activity students follow the CDIO process and work in teams to design and build a “skyscraper”—as tall a building as possible—out of polystyrene and pencils with a limited budget. The building needs to have structural integrity and be able to withstand an “earthquake”, operationally defined as not tipping over when a half litre bottle of water is placed on top and the structure is tilted so the slope is 1 in 10.

The first author participated in the Skyscraper workshop at the 2010 CDIO conference, while the other authors participated in a workshop run by David Wisler during a visit to the University of Pretoria in October 2010. Thus we all had first-hand experience of the activity. In both cases, participants spent about three hours on the activity all in one session.

In the ENGAGE programme we had 275 students that were divided into six classes. Each class met for one lecture and three 50-minute discussion periods per week. The discussion periods are staffed by one lecturer and one student tutor per class. The activity was run during the discussion periods. Students did the conceive phase during the first period, the design phase in the second period and the implement (build) phase in the third period. The activity was carried out with all six classes in the same week, involving a total of 18 teaching periods. It was lead by the third author, who was the course instructor, with assistance from the second author and one student tutor per group.

The discussion periods took place in normal classrooms around the campus with moveable tables and chairs, so all materials had to be carried into these rooms. Space is a problem at the University of Pretoria, with its approximately 40 000 students. Limited space meant that only about five groups could work in a room at one time, resulting in group sizes of about 9 members, which is probably too big. There were a total of 32 groups.

An unforeseen problem we encountered was trying to source the extruded polystyrene foam that is one of the two building materials specified in the Skyscraper template. Most of the polystyrene available in South Africa is expanded, not extruded, which is too friable. Numerous inquiries had to be made before a company was found that sold extruded polystyrene. In future it may be possible to find a suitable local alternative, but it will be a challenge to match the strength, rigidity, cost and low density (which enables the creation of fairly tall structures) of the extruded polystyrene.

RESULTS

Student groups were marked out of 100 according to the marking scheme shown in Table 2. No peer marking was done because of time and staffing constraints.

Table 2
Marking Scheme Used for Skyscraper Activity

Feature	Marks	Feature	Marks
Stability	30	Aesthetics	5
Height	20	Time and organisation	10
Budget	5	Documentation	30

The two criteria on which the largest number of groups lost marks were budget and documentation. Of the 32 groups only 5 scored at least 3/5 for budget. This is probably reflective of a general problem in South Africa that many adults, let alone beginning university students, have very poor personal financial management skills. (Since the global recession there has been a proliferation of debt counsellors.) For the criterion of documentation associated with their design only 5 groups scored at least 25/30, while 9 groups scored 20/30 or less. It seems that many of the students lacked planning skills and were eager to just get on with the building.

We carried out a secondary analysis of the students' performance to identify more clearly where they had problems. The criteria we used for this analysis were:

1. Complete project plans
2. Conceiving constraints
3. Thorough design
4. Following documentation ("gap" between as designed and as built)
5. Time management
6. Evidence of effective group work (backed up by photographs)
7. Focus on aesthetics above functionality
8. Calculations based on physics principles
9. Correct budget calculations and materials list
10. Attention to detail in calculations and materials list (no careless mistakes)
11. Quality of design presentation in drawings and/or words
12. Changes made to design during or after building to meet requirements

Each group's performance was analysed on a scale of 1 (low) to 3 (high) for each criterion. The results are summarised in Table 3.

Table 3
Percentage of groups scoring 1, 2 or 3 for each criterion used for secondary analysis

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1	16	41	16	16	13	9	78	63	38	3	16	47
2	34	28	22	25	38	0	13	6	22	75	25	28
3	50	31	63	59	50	91	9	31	41	22	59	25

The following problems with the groups' performance are evident from Table 3:

- Only half produced a good project plan;
- Less than one third thought through the constraints carefully in the conceive phase;
- More than a third did not produce a thorough design;
- More than a third deviated from their design when they built their structure;
- Only half managed their time well;

- 9% focused more on aesthetics than functionality
- Less than one third did calculations of underlying physics needed for the design;
- Less than half did correct budget calculations and produced complete materials lists;
- Less than one quarter made no careless mistakes in calculations;
- More than one third did not present their designs well;
- More than half of the designed structures did not meet the requirements and had to be adapted.

Informal observations suggest that poor performance on criteria 1 and 2 seemed to be attitudinal. Students did not appear to want to take time for careful planning, eager instead to get on with the building. In some groups too much time was spent discussing the task and allocating roles so they then had to rush. The gap between what was designed and what was built by a number of groups suggests a lack of attention (to the design) and intention (understanding the importance of doing the design). The fact that so few students provided correct calculations of the centre of mass (criterion 8) was surprising given that they had just covered the topic in physics. This could be a manifestation of the well-documented problem of lack of transfer between the domain in which a concept is learned and a different context in which it needs to be applied [11]. Poor performance in criteria 9 and 10 points to lack of care, possibly at least partially as a result of hurrying the task too much. Some errors arose from poor understanding of basic mathematics, errors that should have been detected if group members had checked each others' work. For criterion 11, one of the reasons that many of the designs were not well-presented is that ENGAGE students only take engineering drawing in year 2 and a number of our students arrive from high school with no drawing expertise, even at a rudimentary level.



Figure 1. A heterogeneous student group with their “Skyscraper”

On the positive side, nearly all of the groups functioned well. At high school students are used to having to work in groups. South Africa is a multi-ethnic, multi-cultural society. Interestingly, informal observations suggest that teams comprising students from different backgrounds functioned more effectively than homogenous groups. Delegating tasks among all group members also led to better group functioning.

On a questionnaire at the end of the Physics module, students responded to the statement, "The Skyscraper exercise increased my understanding of how engineers think and work." On a 4-point scale, 78% of students answered "a lot" (1) or "some" (2).

CONCLUSION

The Skyscraper activity provides a very nice introduction to beginning engineering students of the variety of factors that need to be taken into account in an engineering project, including technical, budget, time and team. It exemplifies the CDIO approach to engineering education. For the first year ENGAGE students, who have not yet begun their engineering courses, it enabled them to get a feel for what an engineering project entails, as well as providing an opportunity to apply their physics knowledge and to work in teams.

Two types of difficulties arose, one relating to the organisation of the activity and the other to the students' performance. We found it very challenging to implement the activity with so many students and so few staff in classrooms all over the campus, which involved carrying the materials from place to place from one period to the next. Ideally, it would be better to secure a single venue for this activity. A new engineering building is nearing completion, so this may be possible in future. The small number of instructors also made it difficult to carefully monitor whether students were meeting all the requirements, such as producing correct materials lists and project plans.

The secondary analysis of difficulties displayed by the groups points to a lack of a variety of skills, some of which could be considered general life skills, such as time management and avoiding careless mistakes. Others are related to dispositions, such as wanting to do what students perceive to be the task (creating the structure) without proper planning. Perhaps this is a sign of the times, where young people routinely figure out how gadgets work by trial and error, without having to read instructions or follow any systematic process. Some of the difficulties are related to skills, such as poor drawings. Given the difficulties students displayed, we need to provide ENGAGE students with more structure and support during the Skyscraper activity. To this end, we have designed an additional handout that clearly spells out what students need to do in each period and lists roles for team members in addition to those in the Skyscraper handouts, such as Quality Assurer, Time Keeper, Record Keeper and Financial Manager (see Appendix). Some people may feel that we have provided too much information, but given the developmental needs of our students we think they will get more out of the activity if they are given more structure.

In the Professional Development module in the second semester of Year 1 we provide students with another opportunity to participate in a CDIO activity. The task is to build a crane from Lego components that meets certain specified requirements. Students first work on the internet on their own to learn about gears and levers, then form teams to conceive, design, build and operate their cranes.

We have identified two second-year ENGAGE modules, namely, Graphical Communication and Mechanics (statics), in which we intend to further develop the concepts involved in the Skyscraper activity. For example, in the existing activity students assume that the centre of mass for their structures coincides with the centre of mass of the water bottle. For most designs, this yields a maximum height that is lower than the actual possible height. In

Mechanics we will show students how to consider the effects of the mass of the pencils and polystyrene on the position of the centre of mass.

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APPENDIX: Additional student handout for the Skyscraper activity

Skyscraper Project

Starting from the week of the 16th of May, we will be embarking on a project to build skyscrapers to demonstrate CDIO principles. This documentation gives information to students about the project as well as the assessment criteria that they will be marked on.

Students have been grouped into groups of 4 to 8 members. Each group must choose three team leaders:

1. Overall Project Engineer
2. Design Leader
3. Implementation Leader

Additional roles that need to be filled by other group members are Quality Assurer, Time Keeper, Record Keeper and Financial Manager. More than one student may fulfil each of these roles.

Each group must choose a team name, and assign roles within the group by the end of their last Discussion Class of the week of the 9th of May.

The project will be marked out of a 100. Seventy five (75) marks will be assigned to the group based on their documentation and their skyscraper, 20 marks will be assigned to each group member by other group members, and 5 marks will be assigned for the completion of a reflection questionnaire.

Below is a schedule to help student to know what needs to be handed in at what stage of the project:

1. By the end of the first session, each group should have submitted the Conceive section of their documentation. This involves defining customer needs, and then developing conceptual, technical and business plans to meet those needs, while considering the technology and materials at your disposal, as well as regulations that apply. **(NO DESIGNS MAY BE DRAWN UP IN THIS SESSION)**
2. By the end of the second session each group should have submitted all the Design documents. This includes:
 - (i) Detailed drawing and sketches
 - (ii) A structural analysis
 - (iii) Detailed manufacturing instruction
 - (iv) A construction plan
 - (v) A budget

Students must obtain a building permit by the end of this session in order to proceed with construction in session three. All the above documentation is required to obtain such a building permit.

3. By the end of session three the building must have been constructed and tested.

Laboratory and project based learning in the compulsory course Biological Chemistry enhancing collaboration and technical communication between groups

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ABSTRACT

The aim of this paper was to describe how changes of laboratory training and project based learning were implemented in order to train the students in making a study design, basic laboratory skills, handling of data, technical communication, collaboration and presentation. The implementation of CDIO learning concepts was not directly reflected in the standard course evaluation; however, the students reported an increased coherence and synergy between course elements and an improved academic understanding.

Keywords – laboratory work, technical communication, raw data handling, multi-disciplinary collaboration, data interpretation/presentation.

INTRODUCTION

Biological Chemistry is a compulsory course at 2nd semester for students following the chemistry, food analysis or biotechnology Bachelor Engineering study program at the Technical University of Denmark (DTU). The course consists of a theoretical part, a laboratory part and a project part. Between 24-50 students participate every semester. In February 2009 the course structure was redesigned, and CDIO concepts implemented. Special attention was devoted to designing a coherent series of laboratory exercises to support hands-on and social learning and promote the disciplinary knowledge of the students. Much effort was also put into integrating the learning experiences from the three course elements; theory, laboratory exercises and project work. Active student learning was facilitated by implementing a variety of active experimental learning methods. The CDIO learning concepts were implemented as part of the general implementation of CDIO learning concepts in the B.Eng. study program in Chemical and Biochemical Engineering (1). The implementation of CDIO concepts at DTU started in September 2008 and the initial process has been described by Vigild et al [2] also a number of course adoptions are described in [3] and [4].

Before implementation of the CDIO learning concepts, the course Biological Chemistry suffered from having a poor integration between the theoretical part, the laboratory part and the project part. The laboratory part was conducted applying the 'cook book' principle, where the students followed a detailed laboratory protocol. The evaluation was done after each exercise by having the students reporting their results in groups by filling in their results in premade tables and answering specific questions. The advantage of this approach was that it was very clear to the students what was requested in order to fulfill the minimum requirements. The disadvantages were that the students came unprepared to the laboratory and gained little understanding of the exercises and the workflow in the laboratory. The project part was a theoretical essay dealing with a biological topic with no link to the laboratory part of the course.

As part of implementing CDIO learning concepts we aimed to create a better understanding between the theoretical and practical aspects of the course moreover, we aimed to improve the engagement of the students in the laboratory part of the course. The student should commit seriously to the preparation, the work related to keeping laboratory journals and reporting of results.

THE PROCESS

The theoretical project and the laboratory part were integrated by making a practical/theoretical project concerning antimicrobial resistant *E. coli* bacteria in retail meats (a topic of public interest). Furthermore, this new project was designed to include the practical execution of techniques and biological experiments taught in the theoretical part of the course, giving the students an opportunity to implement and operate their obtained skills and knowledge. The

students now work in groups each responsible for a subtopic (see Figure). All groups collect two meat samples in retail stores based on criteria defined in the class. The samples are subjected to the same set of experiments in all groups. Results are shared between groups based on topic; meaning that the groups do not present their own results, but the results related to their topic on behalf of the entire class. This approach was an attempt to strengthen student teamwork and collaboration.

The students present their subtopic for the entire class prior to the laboratory experiments, and in the end the groups make an oral presentation (20 min) of a prepared poster, followed by an oral examination in front of the class.

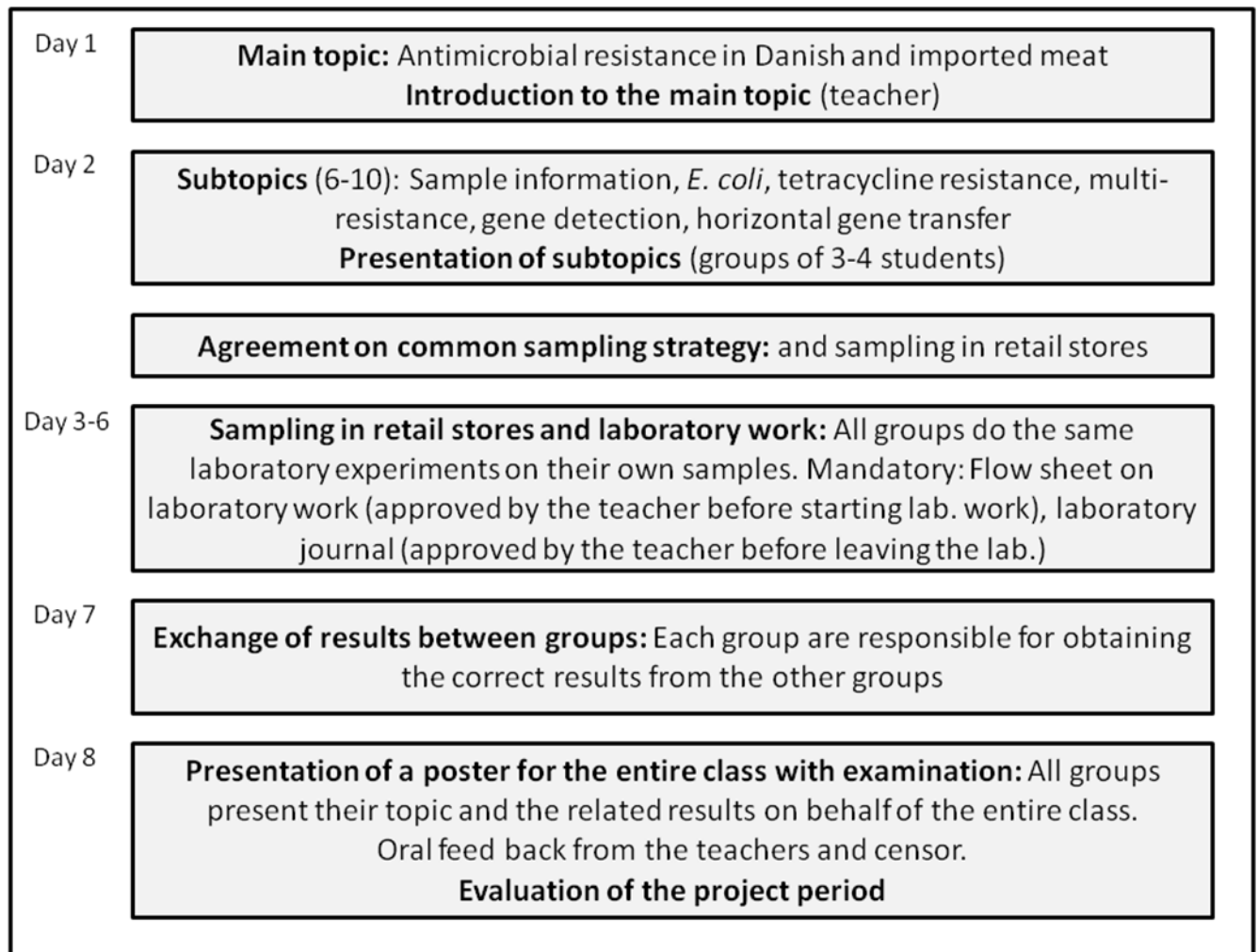


Figure: The elements of the project part divided into days (4 hours one day a week for 8 weeks).

Discussion/Conclusion:

Generally, the students find the main topic interesting, but some students are in the beginning frustrated over their lack of knowledge about their own subtopic. During the project period, the students gain an improved understanding of the topic and understand the laboratory work in greater detail. They work engaged and are forced to take seriously the preparation and laboratory journal work, as well as the technical communication and collaboration. This teaching approach also requires that the students take seriously their obligations to the entire class in sharing results and presenting their topic. They find the oral examination and feedback in front of the class learning full and challenging. In conclusion, this teaching approach is very suitable for introducing CDIO learning concepts on 2nd semester for 15-50 students. The optimal number of students for the project described here is, however, between 20-30 students.

In order to assess the impact of implementing the CDIO learning concept in this course in more absolute terms, we tried to examine the students' evaluation of their perceived outcome of various course elements; overall learning outcome, coherence and synergy between course elements, help and feedback from teachers and the obtained grades at the written examination. No significant measurable impact from the implementation of the CDIO learning concept can be drawn from these course evaluations; however the students did report an improvement in coherence and synergy between course elements and an improved academic understanding. More effort should be devoted to incorporating questions in the standard course evaluation taking CDIO learning concepts into account.

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EFFECT OF REFLECTIVE ASSESSMENT ON INTERNALISATION OF CDIO PRINCIPLES

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ABSTRACT

CDIO initiative aims at creating engineers who can engineer through the use of a product life cycle as an educational framework. CDIO's Standard 11 which refers to the CDIO Skills Assessment focuses on the assessment of student learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge. This paper presents an assessment rubric for a Multidisciplinary Engineering Design module in which the students are required to explicitly reflect on when did they Conceive, Design, Implement and Operate while working in a multidisciplinary team on a given project. To assess the effectiveness of the reflective component of the assessment, two groups of students were surveyed; the first group was assessed on the achievement of their learning outcomes, quality of the project submitted and the interpersonal skills while the second group was asked to reflect on the CDIO process frequently during the semester. The initial results show that asking the students to intentionally analyse their learning experience through the prism of CDIO creates more awareness of the CDIO as a process which can lead to internalisation of the process as a thinking and problem solving technique that can be used when learning other modules that are not design and build by nature.

Keywords – assessment rubric, thinking process, CDIO standards, graduate capabilities

INTRODUCTION

In order to prepare graduates to be ready for the global challenges ahead, Taylor's University (Malaysia) identified a set of capabilities and named them the Taylor's Graduate Capabilities (TGC). These capabilities encompass discipline specific knowledge, cognitive capabilities and soft skills and they are mapped against the syllabus of all programmes offered by Taylor's University [1]. Project Based Learning is widely accepted as an effective technique for engineering and technology education as it provides students with avenues to develop both their technical and non-technical skills while integrating knowledge acquired into its practical contexts [2, 3] and hence, Project Based Learning is identified as the technique the School of Engineering at Taylor's is using to instil Taylor's Graduate Capabilities. Since joining the Conceive, Design, Implement and Operate (CDIO) initiative, the School has subscribed to a Project Based Learning with a product life cycle flavour whereby students enrolled at the School are required to take a Project Based Learning module in every semester of their studies. This is to ensure that students are given enough opportunities to acquire personal, interpersonal, and product and system building skills.

It is widely accepted that one of the major challenges facing the implementation of Project Based Learning is the lack of standard assessment and evaluation rubrics [2]. In order for Project Based Learning to achieve its full potential, not only new teaching methods are required but also innovative supportive assessment and evaluation methods [4]. In this paper, a reflective assessment for a Project Based Learning module is presented with special interest of the effect of the assessment on the internalisation of the CDIO principles.

MULTIDISCIPLINARY ENGINEERING DESIGN MODULE

The Multidisciplinary Engineering Design module is offered to the second year students. In this module, interdisciplinary teams of 5 students from Electrical and Electrical (EE) Engineering and Mechanical Engineering (ME) are created to design and build a product in one semester (14 weeks). There were a total of 109 students which made up 22 teams and each team chose their respective project.

In the Multidisciplinary Engineering Design module, there are six learning outcomes. The mapping of the learning outcomes against the CDIO syllabus is shown in Table 1. The mapping of CDIO syllabus to the learning outcomes is important to show the students competency in terms of CDIO skills.

Table 1. Mapping of CDIO syllabus to learning outcomes of the Multidisciplinary Engineering Design module

Module's Learning Outcomes	CDIO Syllabus
1. Explain the principles of design for sustainable development	4.1 External and Societal Context 4.1.2 The Impact of Engineering on Society
2. Apply the principles of physics to achieve a specific engineering task or to build an engineering artefact.	1.1 Knowledge of underlying sciences
3. Evaluate different approaches to achieve a required end result.	4.5 Implementing 4.5.5 Test, Verification, Validation, and Certification
4. Appraise and defend ideas	2.2 Experimentation and knowledge discovery 2.2.4 Hypothesis Test and Defense
5. Predict outcomes of suggested approaches	2.2 Experimentation and knowledge discovery 2.2.1 Hypothesis Formulation
6. Blend visual and verbal communication using a variety of presentation tools	3.2 Communication 3.2.6 Oral Presentation and Inter-personal Communication

ASSESSMENT PLAN

The achievement of the learning outcomes and the respective CDIO syllabus was evaluated using a variety of methods. These methods included the submission of a design proposal, portfolio, written final report, oral presentation, artefact oral test, and artefact presentation. Table 2 shows the assessment methods and their respective type (whether group or individual assessment). Of all the assessment methods, students were required to self-reflect in the portfolio and oral presentation. The students were

given freedom whether to reflect their learning experience in terms of CDIO lifecycle or not. At the end of the semester, these students were categorised in two groups: reflection with CDIO and reflection without CDIO. On one hand, students who were categorised in “reflection with CDIO” worked on their project and reflected their learning experience based on CDIO lifecycle. On the other hand, the other group of students worked on their project and reflected on the learning experience without considering the CDIO lifecycle.

Table 2 Assessment methods with the respective type of assessments

Assessment Methods	Type of Assessment
Design Proposal	Group
Final Report	Group
Artefact Presentation	Group
Portfolio	Individual
Oral Presentation	Individual
Artefact Oral Test	Individual

Design Proposal

The objectives of the design proposal were to ensure that the students understand the project and have good management for the project. Students were required to submit the design proposal which contained objective of the project, introduction to the project, bill of material, proposed budget, Gantt chart and linear responsibility chart.

Final Report

The objective of the report was to document the technical information of the project. Students were required to submit the report with the abstract, introduction, materials, methods, results and discussion, conclusion and recommendation, and references.

Artefact Presentation

The objective of this assessment was to expose students to demonstrate and explain their product to peers, lecturers, judges and visitors. The assessment was based on the overall functionality and design of the product, teamwork and ability to answer questions.

Portfolio

The objective of the portfolio is to assist students in tracking the progress of their achievement of the module’s learning outcomes through documentation of evidences and reflection. The possible evidences included photographs, journal papers, reports, coursework, technical drawing, video clips, written material, audio presentation, exams and quizzes. The evidences could be either previously graded or not. The evidences should be combined to show a clear picture of how the students related their learning experiences with the course learning outcomes as well as the CDIO stages. The self-reflection is included together with the evidence. To assist students who would like to analyse their learning experience based on CDIO lifecycle, examples of evidences for learning outcomes were suggested as shown in Table 3. Student submitted their evidences by identifying when they conceived, designed, implemented and operated. The evidence submitted would be evaluated as shown in Table 4. Students submitted

one piece of evidence for each level of the five learning outcomes. The levels were categorized according to the Bloom's Taxonomy.

Table 3 Suggested evidence with respect to learning outcomes and CDIO lifecycle

LO	Lifecycle	Suggested Evidence
1	Conceive	<ul style="list-style-type: none"> ▪ Statement and/or proposal of a project that has positive (or at least no negative) environmental impacts when it operates ▪ Statement and/or proposal of a project that provide solutions for environmental and/or energy problems
	Design	<ul style="list-style-type: none"> ▪ BOM with material selected adhering to sustainability principles ▪ Energy audit of the project (how much energy will be used to manufacture it, operate it and maintain it- This should include the energy used to manufacture off the shelf parts)
	Implement	<ul style="list-style-type: none"> ▪ Business plan clearly showing the Business Value (BV) and the Return on Investment (ROI) ▪ Maintain cash flow records
	Operate	<ul style="list-style-type: none"> ▪ An account of what will happen to the different components of the project after the end of its lifecycle (e.g. if solar cells are used, will they be dumped in the environment when the project is no longer in use?) ▪ A list of the waste and/or by-products of the project's manufacturing, operation and maintenance

Table 4 Rubric for portfolio assessment

LO	Level	Mark	Question Cues	Suggested Examples for LO1
1 to 5	Level 3	1 or 2	<ul style="list-style-type: none"> • Evaluate, access, modify, plan, design create, invent, plan, generalize, integrate, measure, conclude, summarize, discriminate, etc. 	<ul style="list-style-type: none"> • Design a better solution to solve problem in the project. • Evaluate the design of the project in terms of sustainable development. • Explanation is supported with clear and directly related evidences.
	Level 2	1, 2 or 3	<ul style="list-style-type: none"> • Apply, analyze, demonstrate, calculate, relate, experiment, change, predict, explain, compare, infer, etc. 	<ul style="list-style-type: none"> • Analyze the problems of the project in terms of the environment impact. • Compare the possible solutions for the problem. • Analysis or explanation is supported with clear and directly related evidences.
	Level 1	1, 2 or 3	<ul style="list-style-type: none"> • List, define, describe, identify, show, label, collect, name, estimate, discuss, etc. 	<ul style="list-style-type: none"> • Giving the definition of the principle of design for sustainable development. • Identify the components of the project that involve in the design of sustainable development. • May/may not give supporting evidences.
	N/A	0		Off topic

Oral Presentation

Students would have to present their digital portfolio orally to the examiners. The content should be the selected evidences for all the learning outcomes that the students had, together with the self-reflection. For those students who reflected with CDIO and without CDIO, they presented their evidences in terms of CDIO lifecycle and learning outcomes, respectively. The oral presentation was adopted to evaluate the student competency for learning outcome 6, which is the communication skill. The areas of evaluation included the content of the presentation, digital portfolio and presentation skills.

Artefact Oral Test

In this assessment, students are required to demonstrate the part of work that they involved individually in the project. The students were asked to demonstrate the artefact of the project to the assessor. The areas of evaluation included the individual contribution, depth of knowledge and quality of product design.

RESULTS & DISCUSSION

This section presents the effectiveness of the CDIO reflective component in the learning experience in the two groups of students. The first group reflected their learning experience without CDIO and the second group reflected their learning experience with CDIO. The number of students chose to reflect with CDIO was 58 whereas the number of students chose to reflect without CDIO was 51. The performance of these two groups of students was first compared using the results obtained from the individual assessments which were the portfolio, oral presentation and artefact oral test. Then the overall grade was compared.

The performance of the two groups of students in the achievement of learning outcomes in portfolio assessment is shown in Fig. 1. In the figure, LO refers to "Learning Outcome". The result shows that students who reflected with CDIO achieved higher average marks in the five learning outcomes as compared to students who reflected without CDIO. It is important to note that the group of students who reflected with CDIO achieved an average mark of 4.6 out of 8 in LO3 to LO5 (2.2 and 4.5 in the CDIO syllabus) as compared to 3.4 out of 8 which achieved by the other group. This shows that by reflecting with CDIO, the students' experimentation and problem solving skills were improved.

Fig. 2 illustrates the average marks of the two groups of students in the oral presentation and artefact oral test. The result shows that for the group who reflected with CDIO achieved 1.6 marks higher than the group who reflected without CDIO in average. The average marks achieved by the group who reflected with CDIO were 7.8 out of 10. Then Fig. 3 depicts the overall grade achieved by the two groups.

Although the results indicate that students who have opted to reflect upon their work through the mirror of CDIO performed better than the other group of students, more work need to be done to ascertain the role of CDIO reflection in impacting the students' learning. Future work will include repeating the experiment with different groups of students as well as comparing the students' performance in other modules to their performance in Project Based Learning module.

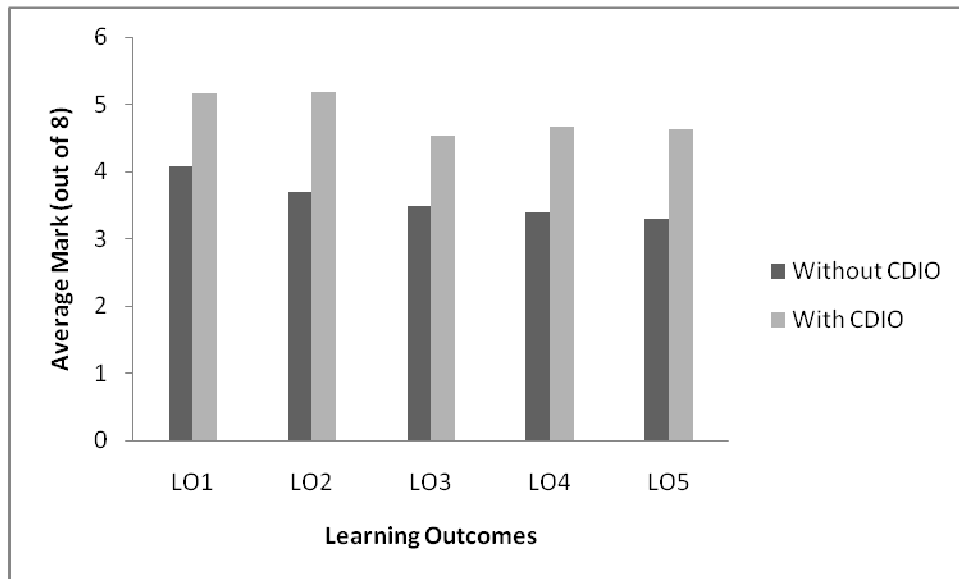


Fig. 1 Average mark against learning outcomes comparison

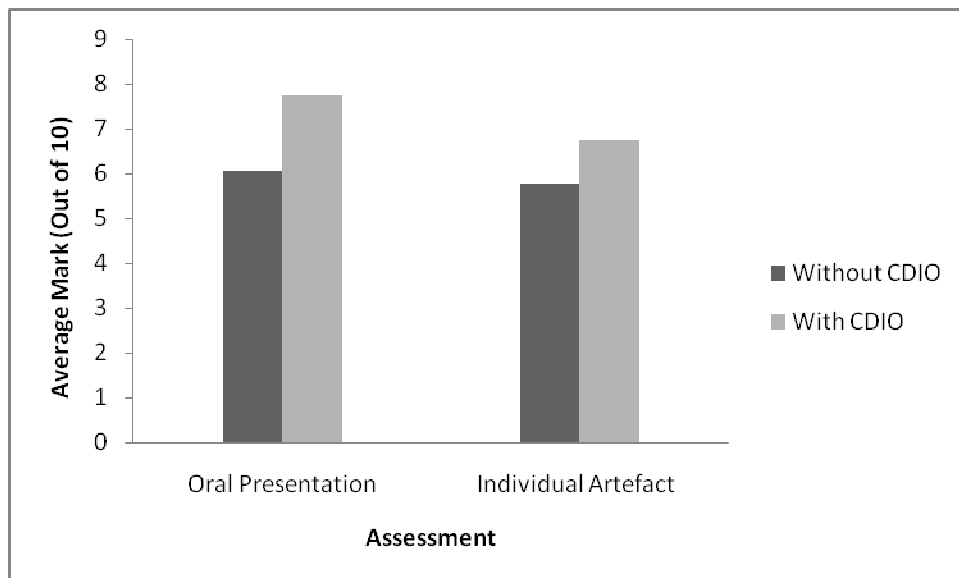


Fig. 2 Average mark comparison for oral presentation and individual artefact test

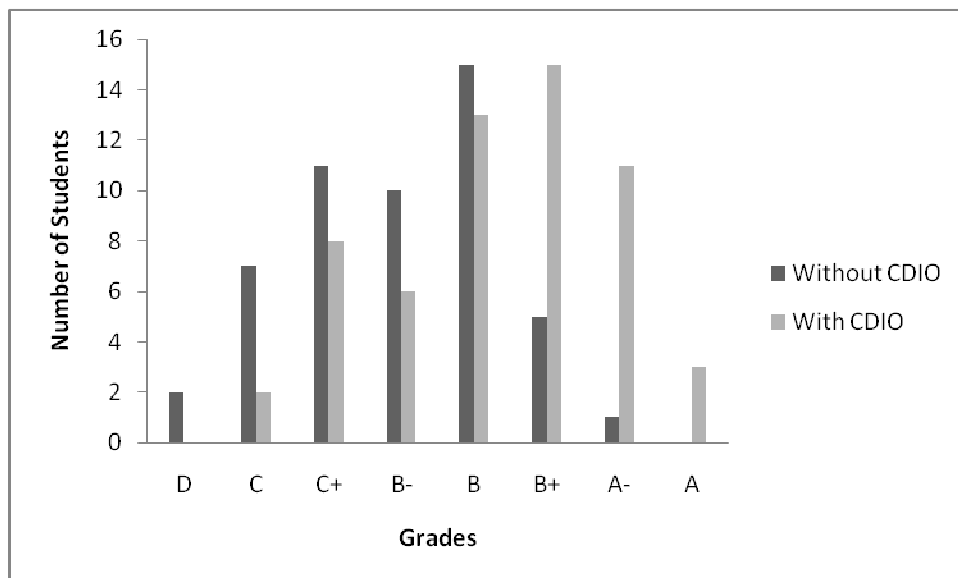


Fig. 3 Overall performance in the module

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CRITICAL SELF-REFLECTIONS ON THE CLASSICAL TEACHING CULTURE IN ENGINEERING

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ABSTRACT

The classical teaching culture in engineering is determined by a deep-rooted belief system that becoming an engineer means having to endure the worst three to five years of your life of hard and boring math, useless abstract theories of physics and a couple of project works for which one slaves day and night for months in order to get things to work. In this paradigm, engineering studies are seen as a kind of initiation time, after which the newly examined engineer will be welcomed into the arms of the engineering brotherhood. No wonder that young people do not find such studies very enticing anymore. In a globalized world full of interesting, catchy, fun and state of the art educational programs, an old-fashioned style of teaching culture in engineering seems rather outdated. But unfortunately, from my own experience I know that it isn't. Teachers in engineering at universities tend to teach in the same way as they have experienced during their own studies. This way they preserve and recreate a teaching culture that resists pedagogical reforms despite substantial criticism from all possible sides.

Why is this? What is it about the classical teaching culture in engineering that makes it impossible for any teacher adhering to it to obtain good or effective teaching? The objective of this paper is to use long-established pedagogical research results on teaching and student learning to analyse the classical teaching culture in engineering. A discussion of this analysis leads to three underlying problem areas: different epistemologies between engineering sciences and engineering undergraduate education, the hierarchy between research and teaching, and the style of examination and its impact on student learning. Finally, possible ways of improvements are discussed. It is also shown that the CDIO Initiative is a valid alternative to the classical teaching culture in engineering, as it allows their teachers to improve the quality in teaching and to make it effective.

KEYWORDS

Engineering teaching culture, teaching style, resistance towards reforms, realism and constructivism, constructive alignment, CDIO Standards.

INTRODUCTION

Traditional engineering education on university level seems very difficult to change or even modify. The classical way of how engineering is being taught at many technical universities follows a tradition with only few reforms since its beginning about a century ago.

Most teachers at technical universities teach more or less in the same way as they have been taught themselves. Usually, they see themselves primarily as engineers, researchers or scientists rather than as teachers. In regard to the need for reforms they are primarily concerned about the content in the engineering programs and less about the way the courses are taught or the role they as teachers play for student learning. Most teachers who teach in engineering are very well aware about the importance to follow the latest developments in their respective technical fields by means of research-activities and co-operations with the industry, companies and organizations. But somehow, they do not regard pedagogy and the field of teaching in higher education as a similarly evolving area on its own.

The objective of this paper is to give a self-critical view regarding the classical teaching culture in engineering from my own experience as a student, PhD-student and most of all from teaching over eight years as an engineer and researcher at the department of computer science at Örebro University in Sweden. My own view on teaching has changed dramatically over the years from a more objectivistic outlook on the content of courses towards a more constructivist understanding about student learning. With other words, my sole concerns about *what to teach* in the beginning of my teaching career have over time expanded to include the questions about *how to teach* and, after becoming interested in the research on higher education, now more and more focus on the problem of *how to support student learning*. This paper contains some of my reflections and conclusions gathered during my own pedagogical journey. I am for example convinced today that in order to be able to reform and modernize engineering programs so that they will attract young men and women, the classical teaching culture in engineering will first have to be changed.

Chapter 2 contains a description of the characteristics of the classical teaching culture in engineering as well as some of its criticism. Examples of reforms are mentioned – the so called Bologna process [2] and the CDIO Initiative [3]. Chapter 3 uses the research results on studies of exemplary teaching that Paul Ramsden has grouped into a set of well-known and generally accepted principles for effective teaching in higher education, [1]. These principles are used to analyse the classical teaching culture in engineering and to compare it to the standards adopted by the CDIO Initiative. Chapter 4 discusses some of the underlying causes in the classical teaching culture of engineering that counterwork a number of principles for good teaching. Chapter 5 suggests possible improvements and changes and mentions interesting examples from various universities.

1. CLASSICAL TEACHING CULTURE IN ENGINEERING

2.1 *Traditional style of teaching in engineering programs in Sweden*

Traditionally, the teaching culture in higher education as practiced in engineering programs in Sweden is characterized by two or more courses read in parallel, which consist of lectures and laborations or exercises. Lectures usually cover the theoretic ground and are taught by professors or associated professors (senior lecturers) to all of the students together. Laboratories are usually carried out in smaller groups (typically around 20 students max) and meant for the students to reach understanding by applying the theory on practical examples, in form of experiments or exercises. Usually, and especially if larger groups of students require several laboratory groups, laboratories are supervised by PhD-students or lecturers and not by the teacher holding the lectures. This teaching model is moreover regarded as

well suited for basic engineering courses, like mathematics, physics or mechanics, which are common at several engineering disciplines during the first year of undergraduate engineering programs. It optimizes the costs by limiting the more expensive teaching hours of a professor and by using cheaper teaching hours for the laboratory hours instead.

This model of differentiating between lectures and practical applications is often even used as the base for allocating teaching resources. In this paradigm, lecture hours, with its higher status, usually count more than laboratory hours. One hour of lecture can for example be multiplied by three to count for the expected amount of time spent by the teacher, while the hours for laboration, exercises or seminars might only be doubled. The two factors three and two are flexibly chosen by the head of the department and can vary in order to divide up the teaching workload among the available teachers.

The main characteristic regarding the style of teaching in this tradition is the view on knowledge as being something objective and absolute, e.g. independent of the teacher or student or their learning context. The role of the teacher is seen to be somebody who is competent and trustworthy to present and explain the knowledge in front of and to the class. It is then up to the students to learn this knowledge so that they can reproduce it in the right way. This transformation of knowledge, selected and presented by the authority of a professor is usually well-defined within the boundaries of the corresponding course. While the laboratories, as part of the course, help students to get a deeper understanding of the knowledge by means of practical application of the theories, the division into different courses creates islands of knowledge that the students find hard to see how they connect. For this reason project-work courses are offered in which the students are expected to solve technical problems by applying the content of all the courses learned so far. It is generally agreed among teaching staff that it is through this kind of applied learning that the students get a deeper understanding of the course material and learn how to think as engineers. Seminars, common in other faculties, such as humanities, pedagogy and philosophy, has almost no tradition in engineering education, at least not in what is referred to as “hard-science” engineering courses.

Traditional assessment in engineering courses follows the division into a theoretical and a practical part. To pass such courses, the students must turn in all exercises and lab-reports and pass a final exam at the end of the course. According to the hierarchy described above, the assessment of the knowledge transferred in lectures by professors or associate professors usually weights more than the practical part (as long as it is not a project-work course). The grade for the final exam with the focus on the theoretical knowledge usually determines the grade for the whole course, while the laboration part is either passed or failed. This outlook on assessment can be seen as the logical result from the traditional view on teaching described above. Since knowledge is seen as something absolute and objective that is presented and transformed to the students, it is up to the students to incorporate it and to show that they have done so at the end of the course. It is then up to the initiated authority (professor or assistant professor) to decide how much of this knowledge each student has incorporated by grading the student’s performance at the final exam. With the professors’ time being so much more valuable than the teachers’ supervising the laboratory work, time for grading is kept to a minimum, typically around half an hour per student and course. This time-limitation usually does not allow for continuous assessments during the course with the exception of short tests in form of automatic graded multiple-choice questions.

2.2 Criticism towards the traditional style of teaching in engineering programs

Criticism regarding the classical teaching culture in engineering as well as the need for reforms have been postulated before. A Swedish study that was ordered by the Swedish parliament and that was partly used to reformulate the official requirements for bachelor and master exams in engineering is the ontology from 1998, called NyIng (new engineer) edited by Linköping University [4]. The report consists of eleven articles that deal with different

aspects regarding the work and role of modern engineers. The common understanding of the different articles is that the role and work of engineers has changed dramatically in the past 10 to 20 years whereas education changes much slower. While higher engineering education programs have adapted well to the changes in technology, the newly examined engineers are being criticized for lacking insights about crucial factors that are part of what one can refer to as “engineering professionalism”. In the NyIng report, a group of engineers and managers discuss the concept of engineering professionalism and find the following major shortcomings in today’s newly examined engineers: communication skills (written and oral), foreign-language skills, team-work, and problem-solving skills of undefined problems under uncertainty.

Some articles in the report are written by well-known people at engineering companies describing the view of these companies about engineering education. Bernt Ericson, chief of research at Ericsson at that time, explains for example his view on higher engineering education in an interview as part of the NyIng report, [5]. Some of his most critical comments are summarized in the following list:

- Focus on “education” where the teacher is the active part should be shifted towards “learning” where the students play the active part. Teachers should become mentors and inspirators instead for holding speeches.
- It is wrong and devastating that newly examined engineers no longer have any intellectual curiosity left. One should be even more inspired to read and learn after studying engineering, not less.
- The setup in which during the first two years students only study basic subjects for the sake of the subjects makes students leave their engineering studies before they are finished. They see no relationship between the different subjects and have no long-time goals for their studies. Young people of today are impatient, they will see fast results. They lose their interest if they have to put in a lot of time for something they do not see what it is good for.

Bernt Ericsson proposes that engineering studies can be made more meaningful and interesting for young people of today if one re-structures higher engineering studies with focus on projects and concrete, real-world problems. And, if tasks are based on real-world problems, the way of working should also be such. This is why engineering students should work in groups and learn how to present their work to one another. Today’s engineers must be able to communicate both within and outside of their discipline. Bernt Ericson as research leader at Ericsson has seen how engineers lack this skill when they for example talk to customers and focus on technical details which are totally uninteresting for the customer who only wants to know how the overall system works. According to Ericson, companies shout after people with interdisciplinary knowledge, who not only are experts in a specialized niche. At the end of the interview Bernt Ericson repeats once more that engineering studies need to improve their attractiveness and that this means that engineering educational programs must be improved, [5, p101].

2.3 Bologna Process

Parts of the findings in the NyIng-report were used by the Swedish National Agency of Higher Studies (“Högskoleverket”) when reforming engineering education at Swedish universities as part of the European coordination of higher studies, called Bologna process [2]. The aim of the Bologna process was to promote and encourage student exchanges between European universities. Besides the harmonization of administrative processes it also propagates a pedagogical framework that is based on John Biggs “constructive alignment” [7,16,17]. Typical for the Bologna process is the shift of focus from the contents in courses towards a description of the learning outcomes for the student completing the course. Learning outcomes are divided into three categories “*Knowledge and understanding*”, “*Competence and skills*” and “*Judgement and approach*” with a thought progression from factual knowledge via application to deep understanding. Learning outcomes for engineering

programs are broken down individually by Swedish universities from a set of common goals defined by the Swedish National Agency of Higher Studies. For example, the learning outcomes of engineering programs with professional qualifications (such as Bachelor of science in engineering, for example) is being stipulated in Appendix 2 to the Higher Education Ordinance, System of Qualifications, see [8]. Looking at these common goals, the points listed under “knowledge and understanding” are very much in line with the traditional view on engineering knowledge to be taught. Next to the “hard-science” technical knowledge common in the traditional teaching culture, other requirements have been added under the headings for “competence and skills” and “judgement and approach” which bring to mind the critics about the traditional teaching culture in engineering as mentioned in the preceding paragraph. For traditional engineers, subjects or issues like “interaction between technology and society”, “economically, socially and ecologically sustainable development”, “teamwork and collaboration”, “oral and written presentations”, “social and ethical aspects”, “responsibilities”, “information literacy” and “preparations for life-long learning” are considered to be “soft”-science in contrast to pure engineering “hard”-science topics. When more or less forced to integrate soft-sciences in engineering programs, such courses are often delegated to the humanities and philosophical departments.

The responsible teachers belonging to the traditional teaching culture of engineering programs found these requests for changes put forward to them by means of the Bologna process as rather awkward. Since no one explained to them the underlying pedagogical foundations and thoughts, they reduced the task for pedagogical reforms to technicalities, such as, for example, rephrasing a course syllabus so that old course contents became students’ learning objectives. This is why nowadays Swedish universities require that all of their teaching staff have successfully completed higher educational pedagogical courses. But since teachers adhering to the classical teaching culture in engineering above all see themselves as engineers, researchers or scientist with a primary interest in “hard”-sciences, it is questionable how much of the “soft”-sciences they actually will acknowledge and incorporate in their teaching.

2.4 CDIO Initiative

CDIO stands for “Conceiving - Designing - Implementing – Operating” real-world systems and products, which is postulated by the CDIO Initiative [3] as the context in which engineering education should take place. The CDIO Initiative can be seen as the answer developed at MIT to the open question of how to meet the new demands posed on modern engineers as described in chapter 2.2 and how to modernize engineering university education to account for these changes. Following an engineering problem solving paradigm, a comprehensive understanding of the skills and knowledge needed by modern engineers was first derived together with faculty, alumni, students and the industry. The outcome was documented by Edward F. Crawley in the MIT- CDIO Syllabus, [10]. The next steps were to look at ways to improve the learning of the knowledge and skills. In January 2004, the CDIO Initiative adopted 12 standards that describe CDIO programs, [11]:

“The 12 CDIO Standards address program philosophy (Standard 1), curriculum development (Standards 2, 3 and 4), design-build experiences and workspaces (Standards 5 and 6), new methods of teaching and learning (Standards 7 and 8), faculty development (Standards 9 and 10), and assessment and evaluation (Standards 11 and 12).” See [11, p1].

With currently more than 50 collaborating institutions in over 20 countries, the CDIO Initiative is becoming more and more of a quasi-standard regarding modernized educational engineering programs. The CDIO Standards were for example used 2005 in a Swedish national evaluation of engineering educational programs by the Swedish National Agency for Higher Education, se [12].

2. ANALYSIS OF THE CLASSICAL TEACHING CULTURE IN ENGINEERING

It is important to be very clear about the fact that there exists no “silver-bullet” or “secret universal recipe” of how to achieve good and effective teaching. However, most teachers and students agree that there exist examples of excellent, high-quality as well as lower quality of teaching. A substantial amount of research investigated the excellent examples of high-quality teaching and came up with a list of properties that can be seen as the characteristics behind “good teaching” [1, p89]. From this list of properties, Paul Ramsden derived 6 main principles that he advocates as the ones to follow in order to improve the quality of teaching. Ramsden clearly points out that there are no universal recipes for good teaching, [6]. But, based on the fact that most examples of good teaching in one way or the other incorporate these principles, they can be seen as a framework of necessary, but not sufficient, criteria for good teaching. This means that incorporating the six principles will improve the quality of teaching but not necessarily result in good teaching. However, neglecting the principles will most likely prevent good teaching as well as the improvement of the quality of teaching.

3.1 Teaching theories and principles behind good teaching

Since most of the teachers, researchers and scientists working at the engineering departments at universities have experienced the traditional teaching model described in chapter 2 as students, this style of teaching seems rather natural to them. It might even be the only style of teaching that they know and therefore carry on. But, different faculties and disciplines follow different teaching traditions. The crucial difference lies in the views about teaching and the teacher’s role. Ramsden for example, describes three distinctive generic ways of understanding the role of the teacher, [1, p109ff]. The foremost common view on the teacher’s role in the traditional teaching culture in engineering as described above is the one that Ramsden describes as the “authoritative transmitter of content, the demonstrator of procedures”. He refers to this style as the *theory one of teaching*. In the *theory two of teaching* focus is on the student’s individual project and less on the teacher. The role of the

Table 1
Summarized overview over Ramsden’s six key principles of effective teaching [1, p93-99]

<i>Principle 1: Interest and explanation</i>	A subject should be made interesting, students should find it a pleasure to learn the subject and be willing to work hard for it, complex matters should be explained in an easy and understandable way
<i>Principle 2: Concern and respect for students and student learning</i>	Effective university teaching requires respect and consideration for students, generosity and willingness to share and pass on knowledge, contrary to making things hard or to frightening students, keen interest in what it takes to help other people learn, pleasure in teaching, delight in improvising
<i>Principle 3: Appropriate assessment and feedback</i>	Quality of feedback on students’ progress is the most relevant question regarding the quality of teaching, teachers should be accessible and be able to question in a deep learning scenario to discover what students really have learned
<i>Principle 4: Clear goals and intellectual challenge</i>	Recognizing a cycle of education from a stage of absorbing, discursive, romantic discovery, stage of precision to a stage of generalization and appreciation, control over learning is shared between the teacher and the students, explaining to the students what must be learned in order to achieve understanding instead of ‘covering the ground’
<i>Principle 5: Independence, control, and engagement</i>	Give students the perception that they have control over their learning, each student is an individual with his or her own way of learning, provide relevant learning tasks at the right level, instructions are necessary in the beginning, but the goal should be to make students self-sufficient. “Learning should be pleasurable, There is no rule against hard work being fun”, [1, p 98].
<i>Principle 6: Learning from students</i>	A teacher should never take the effects on students for granted, should try to diagnose and clarify possible misunderstandings during the scope of the course, see the evaluation of teaching as an integral part of teaching.

teacher is to be a supervisor that helps as the link between theoretical knowledge and practical experience. Project-work courses in engineering programs are usually run in this way. The CDIO-initiative is a good illustration for this style of teaching. Finally, in the *theory three of teaching*, learning is understood as something the *student* does, instead of something that is being *done* to the students. It recognizes that teaching and learning are two sides of the same coin and that the relation between teacher and student is relational and rather complex in which teaching is defined as making learning possible. Ramsden considers this one as the ideal style of teaching that might not always be realizable but definitely worth to endeavour.

Ramsden's six main principles behind "good teaching" (see Table 1) can be seen as dimensions in which to improve the quality of teaching. Using these dimensions in a polarity profile diagram it can be used to illustrate the strengths and weaknesses in teaching. It also allows comparing the traditional teaching culture in engineering as described in chapter 2, to the 12 standards adopted by the CDIO Initiative.

3.2 Polarity profile diagrams comparing the traditional teaching culture in engineering with the CDIO-Standards

In the proposed polarity profile diagrams each principle from Table 1 is represented by an axis pointing outward in the direction of possible quality improvements. Such diagrams can for example be used to document the development of individual teachers over the years by his or her teaching experiences and involvement with pedagogical questions. In the diagram the teachers development will result in an "enlargement" of the figure along the different axes over the years. Since the teaching culture in engineering more or less sets the framework in which teachers and students meet, it becomes interesting to look at a polarity profile diagram for the overall teaching culture in engineering and to compare it to the CDIO Initiative. However, no quantitative analysis has so far been carried out and the following analyses and drawing is purely qualitative and rather subjective.

The traditional style of teaching in engineering programs puts a lot of focus on the first principle. Most teachers at engineering universities find their subjects interesting and are very engaged regarding the content of it. However, the division into theoretical and practical parts, which are not always synchronized, place obstacles in the student's way to deep learning. Student engagement is usually larger in project works due to more integrated learning with a closer interaction between theory and its application as is the case in CDIO programs. Other clear disadvantages of dividing teaching into different parts with different teachers interacting with the students are the resulting difficulties in giving consistent feedback to the student (principle 3), to control the learning in order to achieve understanding (principle 4), or to provide relevant learning tasks at the right level (principle 5). Regarding the concern and respect for students and student learning (principle 2), Ramsden explicitly mentions the teaching traditions at engineering and medicine as examples for putting pressure on lecturers to act in a certain way:

"The archetypical arrogant professor, secure in the omnipotent possession of boundless knowledge, represents a tradition that dies hard. Certain lecturers, especially new ones, seem to take a delight in trying to imitate him", [1, p 94].

Professors and associated professors who see themselves primarily as scientists or engineers doing research and who hate to teach also tend to run in and out of their lectures with almost no personal interaction with their students. They simply lack interest in and compassion for students or student learning. But since teaching has a much lower status than research, they often don't need to care, and by this way make sure that they will not be asked to teach more than the minimum. At the same time it is very important for teachers to understand the students of today. As John Biggs so well documents on a video on constructive alignment [13] there are at least two types of students. In the video they are called Susan and Robert. Susan represents the ideal, self-going student who, given a list with the course literature, basically learns herself, driven by her own interest. Robert's main

motivation for studying is the piece of paper with the exam at the end of the undergraduate program. While a few decades ago students were a homogenous group of self-learning Susans, the Roberts now are in majority. Focus on the knowledge to be transferred instead on the individual student also results in the overhanging risk of “breakneck attempts to ‘cover the ground’” (principle 4). Everything in the course books is seen as equally important. This is rather understandable, given the fact that only few of the teachers at engineering departments actually ever worked as engineers outside the university. They lack experiences from real-world examples and therefore find it difficult to prioritize.

Ramsden summarizes the consequences of *theory one of teaching* with the following words:

“All this is rather bad news for the traditional lecture, practical class, and tutorial, as well as for orthodox approaches to the professional curriculum, [...]. It seems that we often encourage poor learning at university through over-stressing individual competition while at the same time using teaching methods that foster passivity and ignore the individual differences between students”, [1, p98].

Learning from students (principle 6), is usually done in the classical teaching culture in engineering by means of course evaluations at the end of the course. If misunderstandings occur during the courses, the students usually find ways to ask the teacher for clarifications.

Figure 1 shows the qualitative profile diagram as a result of this qualitative analysis of the traditional teaching culture in engineering in regard to the six principles. If a principle is an important part of the traditional teaching culture its correspondence was set to *strong*. If a principle is not part at all or counteracted by the classical teaching culture, its correspondence was set to *weak*. Principles that are neither set to *strong* or *weak* are set to *neutral*. In this way, principles 2, 3, 4, 5 have been set to *weak*, principle 6 to *neutral* and principle 1 to *strong*. One can look at the resulting figure in the middle of the diagram as a representation of the framework for good teaching provided by the classical teaching culture. As such, 4 out of 6 principles are not part of the framework. Of course, individual teachers can always “brake” out of this framework and still realize good teaching, but it is interesting to note that if they do, they will to a large part work outside the traditional teaching framework.

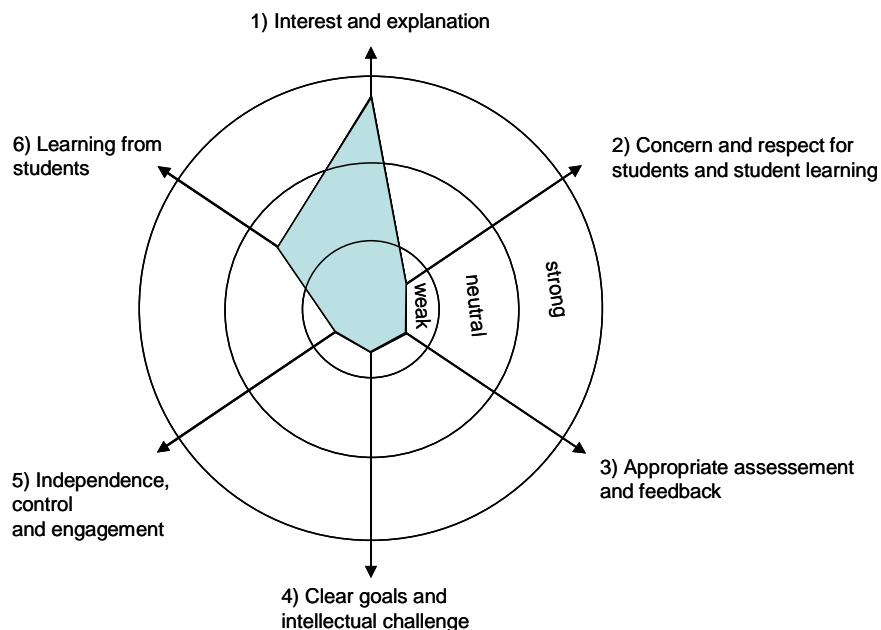


Figure 1. Qualitative profile diagram of the traditional teaching culture in engineering

One of the major goals of the CDIO Initiative is to re-emphasize teaching engineering practice in regard to the teaching of engineering sciences in order to better prepare the graduating students for real-world engineering tasks. This is proposed to happen within a context for engineering education that follows the “*Conceiving – Designing- Implementing – Operating*” model. In this model it is essential that theory and practice are combined and that all the skills needed by a modern engineer are being taught in an integral way. This creates a cultural framework which supports all of Ramsden’s key principles as shown in Table 1.

To make the subjects interesting (principle 1) is at the core of the CDIO Initiative. Students have a lot more pleasure to learn and are more willing to work hard in CDIO programs. Several of the CDIO Standards ensure this: the appropriate context for engineering education (Standard 1), the learning outcomes (Standard 2), the curriculum development (Standards 3 and 4), and the design-build experiences, and workspaces (Standards 5 and 6), integrated learning experiences (Standard 7), active learning (Standard 8), and the enhancement of faculty skills (Standards 9 and 10).

Some of the CDIO Standards have a clear student-centred view on teaching, showing concern for the students and trying to make learning interesting and rewarding (principle 2): learning objectives that describe what the students should know and be able to do at the end (Standard 2), an introductory course in the beginning to prepare students (Standard 4), promotion of early success in engineering practice (Standard 5), student-centred workspaces (Standard 6), and active learning methods (Standard 8).

Standard 11 in the CDIO Initiative mentions that effective learning assessment (principle 3) should use a variety of methods according to the learning outcomes. Besides written and oral tests common in the classical teaching culture, the following methods are also mentioned: “observations of student performance, rating scales, student reflections, journals, portfolios, and peer and self-assessment.”, [11, p 8]. Combining theory with practice in the CDIO context also generates immediate feedback to the student (principle 3) when realizing that something does not work the way it was intended. The CDIO Initiative is very important in respect to setting clear goals and intellectual challenge (principle 4). Much of its efforts have been spent on the joint agreement between the academic and industrial world regarding the clarification and key-priority of the content of engineering programs. Other important aspects are the focus on integrated and active learning, the design-build experiences, and the enhancement of faculty teaching skills. Hence, CDIO Standards 2, 5, 7, 8 and 10 clearly support this principle.

Since the CDIO Initiative adheres to constructive alignment, knowledge and skills are not regarded as something absolute or objective. Instead, it needs to be constructed in a given context by each individual student. The focus on design-build experiences (Standard 5), learning environments that support hands-on learning (Standard 6), and the process of metacognition (Standard 8) all can be seen to support principle 5.

Learning from students (principle 6) is not directly addressed in an own CDIO Standard, perhaps with the exception of Standard 12 on program evaluation which mentions the need to *gather data from students*. Other standards imply indirectly learning from students. Standard 8, for example, is about active student learning, while Standards 9 & 10 are about the enhancement of teaching faculty.

Together, all CDIO Standards refer to all of the six key principles. Of course this does not mean that all CDIO-engineering programs automatically are superior to more traditional engineering programs. What it means is that the CDIO Standards allow for a framework for good teaching that is larger than the one for traditional teaching in engineering, since it includes all six principles of effective teaching, as figure 2 qualitatively illustrates. It also means that a teacher of CDIO engineering programs can realize good teaching within the CDIO-standards. However, many CDIO-educational programs are probably run by departments which in their structure and organization still adhere to the classical teaching culture in engineering. To operate and maintain CDIO-programs with its full potential in such “stunted” environments probably requires a lot of extra energy.

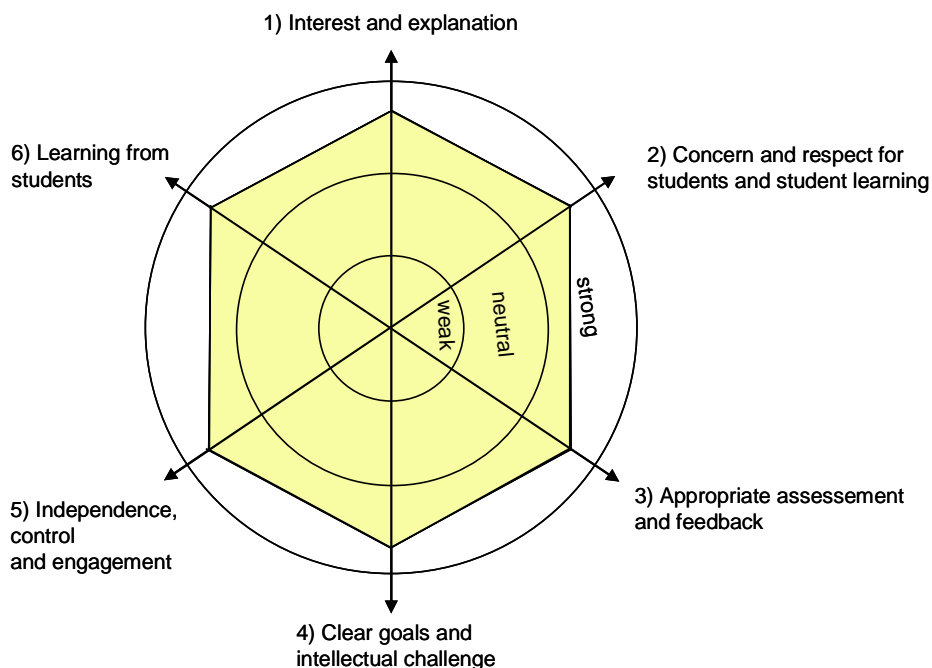


Figure 2. Qualitative profile diagram of the framework for effective teaching possible in CDIO engineering education programs

3. DISCUSSION

The analysis in the preceding chapter indicates that 4 out of 6 principles that research finds necessary (but not sufficient) underlying factors for effective teaching are not really supported within the framework of the classical teaching culture in engineering. With other words: teachers who adhere to the traditional way of teaching in engineering cannot realize effective or good teaching in their courses, no matter what they do! If they want to reach effective teaching they will have to look outside the classical teaching culture. As the example of the CDIO Initiative shows, there are actually more and more engineering programs doing so as well. CDIO does not define how a teacher should be teaching but its Strategies refer to all of the 6 principles of effective teaching so that a teacher actually can implement them in his or her course within the CDIO framework.

Since the classical teaching culture in engineering still is very strong and dominating for most of the engineering programs, the question is how it could be changed to support more of the principles for good teaching. This way, teaching could become more effective within the existing framework and the quality of teaching would improve. Teachers and students would have more fun and learn more. In this chapter, possible underlying key-problems are discussed, e.g. constellations and mind-sets in the traditional teaching culture which counterwork the principles 2, 3, 4 and 5 for effective teaching. The next chapter looks at examples for possible improvements. The key-problems in question are: the hierarchy between research and teaching, focus on teaching as transformation of knowledge from the teacher to the students, and style of examination and its impact on student learning.

4.1 *Hierarchy between research and teaching*

The structural organization of engineering departments sometimes separates researchers and teachers into two different groups. While the researchers by their working contract are “forced” to teach part-time, the more or less openly declared policy is that researchers shall not be disturbed too much in their research by teaching tasks. Economically it is very costly

to pay professors to teach undergraduate courses compared to full-time teachers or PhD-students. This is also why senior researchers often only teach the theoretical part in a course, leaving the practical laboration parts to others. On the other hand, senior lecturers with full-time teaching positions have according to their working-contract the “right” to do research at, for example, 20% of their time. They are formally part of a research group but practically can not attend any meetings because of their high teaching load. They are usually not either included in research proposals since external money should primarily go to pay the wages for researchers who are employed on project bases. The amount of teaching put on senior lecturers usually leaves no time for them to do research.

In Sweden however, the law on higher education clearly stipulates the connection between teaching and the “awareness of current research and development work” for which the teachers must be a guarantee for. The role of universities has traditionally been seen as the place where teaching and research takes place. It is research that forms and stands on the scientific ground upon which university studies are legitimized. It is the connection between research and teaching that provides the level and quality that is expected of university studies. This is why teachers also need to be active researchers.

On the other hand, there is much to gain for researchers being involved in teaching. Teaching is known to be the best form of reaching understanding. To explain complex ideas to undergraduate students is quite a challenge, which, if one succeeds, also benefits one’s own research by providing clarity, priority and simplicity to one’s own mind. Teaching graduate students can be interesting for testing new research ideas. Teaching in the way as proposed by Ramsdens *teaching three theory* is making the researcher attentive and open to other views, the context, other questions as well as to totally new ideas. Effective teaching can be very enriching on a personal and relational level. It helps keeping the right perspective on life as well as preventing oneself from becoming too one-sided on one’s own projects. Baldwin describes in her report on the teaching-research nexus, that “academics have been known to report that being asked to teach a subject in a new area has opened up unexpected lines of inquiry that have led to fruitful new research agendas” [15, p 4].

Finally, only very few researchers will ever get the Nobel-prize or even become internationally successful and well-known professors. This means that full-time teaching positions will be most realistic for most of the ambitious younger researchers who decide to stay and work at a university. Teaching, like any other trade is learned by doing, it should therefore be practiced together with people who have more experience than oneself. This is one of the main reasons why teaching and research is combined at universities; it allows younger and older people to work together and to profit from each other.

Summarizing, one can conclude that the strict division between researchers and teachers potentially lowers the quality of both – the research as well as the teaching carried out at a department.

4.2 View on teaching as transformation of objective knowledge

The view of knowledge as something objective and absolute is very strong in the engineering culture in general. The relationship between hard-science and realism is obvious and even historically deeply rooted. This is probably one of the main reasons why traditional view on teaching at engineering universities is still seen as a transformation of knowledge from the teacher to the students. Ramsden calls this a *theory one teaching* approach which according to research leads to consequences like, for example, students: who are less interested and motivated in their studies, who spend less time than expected studying, who don’t finish their studies in time or quit after the first year, who don’t really understand the fundamental ideas in their subject of studies, who are poor writers and communicators, who learn for the final exams instead for wanting to learn more about what interests them most, and who are not so good at solving unstructured real-world problems. Interestingly enough, these are also very much the observations regarding engineering students mentioned in the interview with Bernt Ericson, research leader at Ericsson, (see chapter 2). It is also characteristic for the *theory one teaching* approach to blame the students for these shortcomings!

In less natural-science and engineering oriented disciplines of science, especially in humanities and pedagogy, knowledge is instead seen as something that is being constructed in a given context, according to constructivism. Students construct the knowledge as part of their learning and dependent on their context. The role of the teacher is to support student learning, which corresponds to the *theory three teaching* approach described by Ramsden. This is more or less what constructive alignment is all about.

4.3 Style of examination and its impact on student learning

As mentioned in chapter 2, the traditional way of examination at least of more technical - and mathematical-oriented courses, are written final exams. This tradition is based on the myth that the final written exam is the best and most just way of examining technical and mathematical knowledge. Most teachers might not at all be aware about the impact of final written exams on student learning if they never have asked students about their learning strategies. Grading only by means of final exams can have devastating effects on students learning. Research confirms that there is clear evidence between different approaches towards assessment and the quality of student learning. In order to enhance student learning, more developed models of assessment should be used, [1, p 186].

4. POSSIBLE IMPROVEMENTS AND CHANGES

The analysis of the classical teaching culture in engineering indicates that there is space for improvements. Three main problem areas were identified in the preceding chapter: The objective of this chapter is to look at possible improvements and changes to each one of these main problems.

5.1 Constructive alignment

With the Bologna process, all European universities adopted constructive alignment as the underlying model of teaching. Even engineering programs were asked to define learning outcomes, describe course activities, and think about assessment for the whole program as well as for single courses. The idea was to create transparency between these parts of teaching which together form the context in which students construct their knowledge, understanding, competence, skills and judgement.

The question that perhaps was not given enough attention is how a research field like engineering sciences that in its core and history belongs to realism can or should be taught according to constructivism. After all, realism and constructivism are in many aspects two rather contradictory epistemologies.

Engineering teachers who, like at Swedish universities, are sent to pedagogical courses need to become aware of this difference. Engineers might need to learn that there exist other epistemologies besides realism. And pedagogy teachers in higher education might need to consider the implications of realism in engineering sciences as well as in society.

At the same time, it is also important to note that the goal of undergraduate studies in engineering is not to educate scientists but engineers. Looking at the requirements for modern engineers and the goals for undergraduate engineering studies as discussed in chapter 2, the role of engineers today is mainly to work together with others in using technology and to solve technical problems within society. If one agrees that technology is an important part of our society and that, as a socio-cultural phenomenon, technology is being developed and used in relation to the values and needs of society (see [18]), one might also agree that the use and development of technology to a high degree is constructivistic.

As a consequence, the socio-cultural aspects of technology and its use should permeate engineering education programs. Not only should the teaching of theory and practical skills go hand in hand, it should also be embedded in a discourse on why or why not certain technologies were developed and used in relation to society. While humanities play an

important role in such discussions, engineers have to take the main responsibility for leading them. If they do, they will also see that constructivism actually does play an important part in engineering, and constructive alignment will start to make sense. For the classical teaching culture in engineering, this means that theory and laboration should be taught with relation to project works that can be related to the society we live in. The courses should be given by a single teacher or by a group of equally engaged and prepared teachers. Instead of covering everything in the textbooks, students should be given the possibility and means to try out things for themselves, to chose between different tasks or to provide own examples in the area of their interests. Listening to the students, helping them in their learning so that they can fulfil the course objectives also means that the teaching should continuously be adapted and improved, even during a course, se [19, 20].

A proof that engineering education actually can follow constructive alignment are the CDIO engineering education programs. A closer look at the 12 CDIO Standards [11] shows that they can be grouped together according to the main topics in constructive alignment in the following way:

- Learning outcomes or learning objectives: Standards 2 and 3
- Course activities: Standards 4, 5 and 6
- Assessment: Standard 7

5.2 Assessment used to improve student learning and teaching

If an approach to assessment is chosen that tries to understand the processes and outcomes of student learning in order to improve teaching and student learning during the course, then final exams are questionable and even contradictory. Research shows that final exams can prevent students from deep learning and understanding. Instead, more developed models of assessment should be used. E.g. models, that help to detect misunderstandings early on and that monitor the students' deep learning and understanding. With more elaborated models of assessments students can be helped to learn more effectively, while at the same time giving the teacher feedback which can be used towards improving the quality of teaching.

Engineering education has one very important advantage that many other academic disciplines are lacking: everything that is being taught in engineering can be applied and demonstrated immediately! Engineering is applied science and should therefore be taught that way. The difference between a technician and an academic trained engineer lies in the degree of understanding of the underlying fundamental ideas. Very generally spoken, a technician is expected to learn how to use technology while an engineer should be able to explain and analyze it. Hence, for an engineer deep-learning and understanding is very crucial. This is why another kind of assessment than the one based on final exams should be used. If one looks at engineering working places, a good engineer is known as such without asking him or her to sit in a confined room for a couple of hours at the end of the month and writing answers to questions. Instead, their working situation provides various possibilities to show how much they can, for example when:

- working in interdisciplinary teams together with different engineers and with non-technical personnel,
- interacting directly with customers,
- they need to explain technical systems on different abstraction levels all the way from general overviews to technical details, orally as well as in writing, in different languages,
- they depend on documentations that other engineers have written and when they document their own work, and
- they have to understand and solve technical problems that they have never solved before.

One of the main requirements on engineering education is that it shall prepare the students towards a working life as engineers. A change of assessment models from final exams to something that would help students to become good engineers would therefore be appreciated. For more concrete information how to assess for understanding see for example Ramsden chapter 10 ([1, pg. 176-206]) and Brown and Glasner [9, 21-32].

5.3 Combining research and teaching

Most famous universities in the United States as well as in Europe and other parts in the world show a clear conviction regarding the importance that all of their academic staff including teaches carry out research. While some faculty members do more teaching or research at different times, there is always a common feeling of belonging to the same department. The separation of researchers and teachers at some departments creates two very different organizations in which staff-members no longer know each other and the exchange of ideas is being limited. The main reason for the separation is mostly economical. In Sweden, research has to mainly finance itself by means of external funding while teaching is financed by the state. Both “sides” are asked by the management to keep their budgets in balance which means that teaching researchers have to be paid from the teaching budget. However, an economical separation of budgets does not necessarily imply an organizational partition. Researchers and teachers can very well work together on common tasks and projects within the same department. After all it is up to the management to determine how they want to organize the department. They could, for example, value the possible financial benefits or the possible synergies in resources of a unified department.

A report by Gabrielle Baldwin from the University of Melbourne illustrates how some universities work consciously towards combining teaching with research, see [15]. Baldwin identified in her report nine principles to guide teaching and learning based on the convictions that “at higher education level, you cannot be a good teacher unless you are also a good researcher” and that “research, after all, is a form of learning”. The list of identified principles contains the following items, all of which are explained in more detail in Baldwin’s report, [15, pg 4]:

- drawing on personal research in designing and teaching courses,
- placing the latest research in the field within its historical context in classroom teaching,
- designing learning activities around contemporary research issues,
- teaching research methods, techniques and skills explicitly within subjects,
- building small-scale research activities into undergraduate assignments,
- involving students in departmental research projects,
- encouraging students to feel part of the research culture of departments,
- infusing teaching with the values of researchers, and
- conducting and drawing on research into student learning to make evidence-based decisions about teaching.

5. CONCLUSIONS

According to research on higher education there are six necessary (but not sufficient) principles for improving the quality of teaching in higher education. An analysis of these principles regarding the classical teaching culture in engineering has shown that 4 of these principles are more or less neglected. This means that teachers adhering to the traditional teaching culture in engineering cannot possibly obtain good or effective teaching.

Underlying reasons were identified in the view of knowledge as something objective and absolute, according to the epistemology of realism common in engineering sciences. Teachers at engineering universities see themselves rather as engineers, researchers or scientists than as teachers. This leads to a conflict between different epistemologies: hard-sciences such as engineering towards soft-sciences such as pedagogy. Research on teaching in higher education belongs to the epistemology of constructivism, where knowledge is regarded as something being constructed by students in their learning context. The role of the teacher becomes more like one of a coach who supports the student’s constructive learning, for example by means of clear goals, continuous feedback and transparency between learning objectives, course activities and assessment. This is also known as *constructive alignment* which can be seen as an accepted standard for teaching in higher education today. In Europe, for example, constructive alignment is the underlying

pedagogical framework of the so called Bologna process, the coordination of higher studies to promote and encourage student exchanges between European universities. As part of the Bologna process, all universities in Europe, including engineering education programs, were asked to adopt constructive alignment in their teaching. But as long as engineering faculty is “trapped” in realism without the awareness of the epistemological difference between engineering science and engineering education it is questionable if the classical teaching culture in engineering can ever be reformed. Instead, it might be more likely that new alternatives for engineering education, like for example the CDIO Initiative, will attract more and more participating engineering programs. The 12 CDIO Standards refer to and more or less include all of the six main principles for improving the quality of teaching while adapting constructive alignment. This means that teachers in CDIO engineering programs actually are given the chances to obtain good and effective teaching which are lacking in the classical teaching culture in engineering.

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Explorative Evaluation of Courses in a New Bachelor Program

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ABSTRACT

Many course evaluations tend to focus on teacher performance and whether students like or don't like the course or the teacher.

An explorative evaluation method has been developed and tested. This method has emphasis on how and when students learn during a specific course and which learning activities enhance the learning.

This explorative evaluation method is closely connected to the course evaluated and is therefore meaningful for the students. The method has been tested on both interdisciplinary CDIO-projects and traditional introductory programming courses in the new Bachelor Program in Healthcare Technology at Engineering College of Aarhus.

This paper presents the method and the results from two evaluations of a programming course in first semester and two evaluations of an interdisciplinary CDIO-project course in third semester. The evaluations took place in January 2010 and January 2011.

KEYWORDS

CDIO Program Evaluation (standard 12), Explorative Evaluation, course evaluation

INTRODUCTION

In august 2008 a new Bachelor Program in Healthcare Technology started at Engineering College of Aarhus.

The Program contains 3 equally weighted disciplines on the first 4 semesters: Biomedical engineering, Software engineering and Healthcare (physiology, pathology, humanities and social sciences). The fifth semester is internship in a national or international engineering company or at Department of Clinical Engineering or a research facility at a hospital. In the last 2 semesters the students select optional courses and make their bachelor project.

This article focus on evaluation in the software engineering discipline, because experience shows, it is the most difficult discipline the students meet in this program. Software engineering courses contains very abstract concepts that are difficult to relate to previously learned skills. The students find that learning programming is like learning a new language without a dictionary, and the teachers find that these students are very hesitating in trying to work on their own. In that respect they act different from students in the ordinary Software Engineering Program. The teachers who are experienced in teaching have been very much challenged.

The students tend to blame the teacher, when they find a subject or task difficult to learn. Besides that many evaluation methods like questionnaires tend to evaluate the teachers performance, teaching skills or personality [1].

The challenge is to develop and test a method with emphasis on how and when students learn during a specific course and which learning activities enhance the learning. It is important to involve the students, listen to their reflections but also to have a dialog with the students and make them reflect on their own role and influence on the course and their learning process.

THE EXPLORATIVE EVALUATION METHOD

In a workshop a common learning path (Figure 4) of the course or project is generated through a dialog between the students and teacher(s). The dialog is guided by a process guide. The picture generates a common reflection on the learning process and this leads to some recommendations for the future development and implementation of new learning initiatives in the course.

Preparation for the workshop

The evaluation is performed at the end of the course. A group of randomly selected students are invited to participate in the workshop. The students should represent the different groups of students in the class (gender, age, professional level, ethnicity etc.) The size of the group is 6-8 students because it is difficult to create and get at clear picture of the learning path with a larger group.

Find a nice room where you will not be disturbed, make arrangements for coffee and cake or fruits to make an informal and good atmosphere.

Before the workshop, the teacher(s) create(s) a timeline with the course subjects listed (Figure 1 and 2).

The Workshop

The duration of a workshop is 1½ hour. The process guide introduces the students to the method. They should understand that students and teachers are on a common exploration tour to find out about this learning path, what happened, what did students and teachers experience (without interpretation [2]) during the course. Experiences are illustrated by the symbols (Figure 3). It should be clear to the students that everybody listens to each other and that the outcomes from this evaluation will be used to improve their courses in the next semesters. The teacher(s) participate(s) in the workshop on equal terms with the students.

The workshop is divided into four parts:

1. An individual reflection on the subjects and learning outcomes. It takes around 20 minutes. The participants get an A4-paper with an empty learning path (figure 1 or 2) and some stickers with the symbols selected for the evaluation (Figure 3). Everyone have to reflect individually. The teacher(s) focus(es) on their experience with the reactions of the class through the course. During this part some relaxation music is played.



Figure 1. A learning path for ST1ITS1-E10

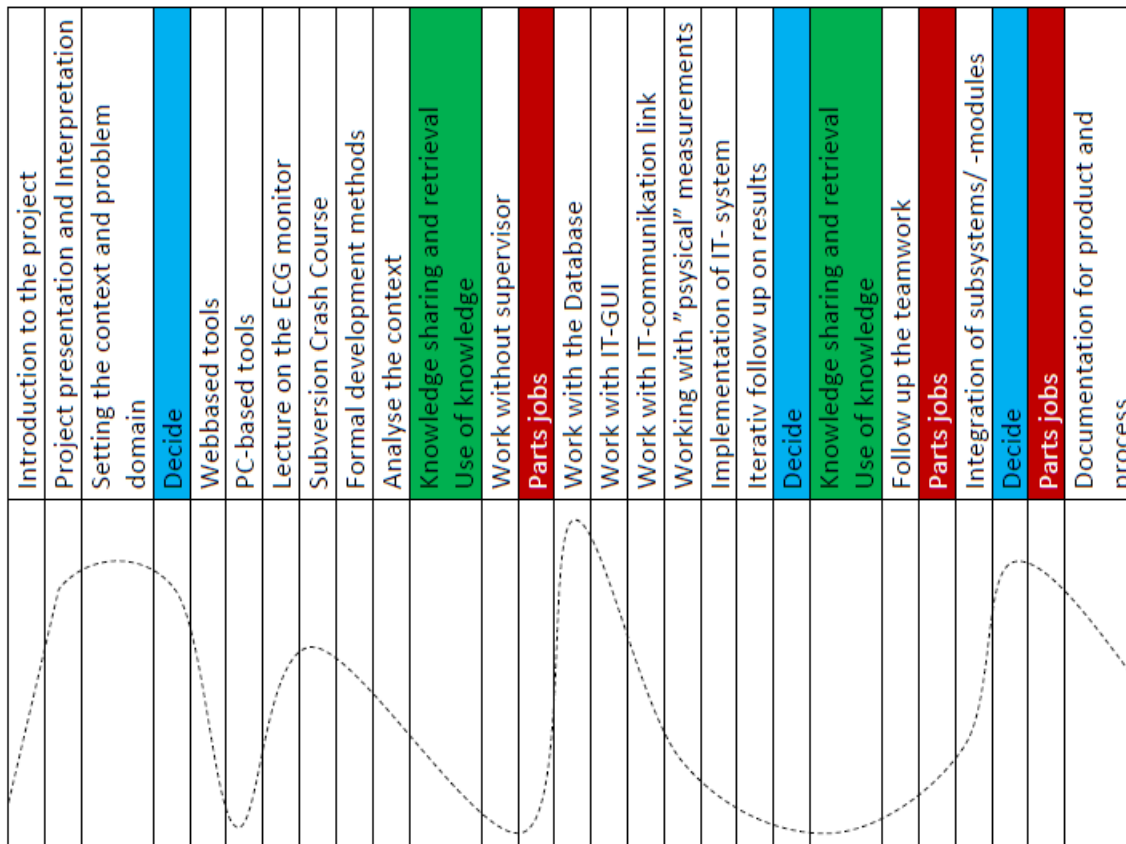


Figure 2. A learning path for the project course ST3PRJ3-E10

2. Generation of the common learning path. The students add stickers to a large paper with the learning path as shown in figure 1 and 2. During that process they add some comments to some of the stickers. The teacher(s) do(es) the same. When everyone has added their stickers, the process guides identifies some patterns from the common picture and list these at a whiteboard. The students help prioritizing the list and a couple of items are selected.
3. Reflection on selected patterns from the learning path in smaller groups. The group of students is divided in two groups (3 to 4 students in a group) and each group gets a subject from the list and makes a brainstorm for ideas for improving the course.
4. Reflection on the evaluation process. The process guide asks the students for comments on the evaluation process, and thanks for their participation. At last the teacher(s) promise to create a summery for all participants of the course, with the changes for the next conduct of the course and elements to bring for the subsequent course.

During the creation of the learning path (parts 1 and 2) the following categories are used (more can be added if relevant):






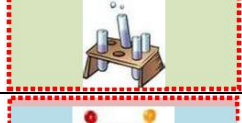
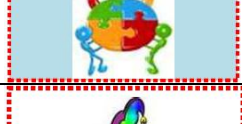

a		AHA – when did you collect the treasures?
b		Time Pressure – when did you feel the time pressure?
c		Workload – when did you feel a heavy workload?
d		Clarity – when did you know the goal and contents of the course (+ on the sticker)? When were you uncertain about the goal (-)?
e		Reading – when did you find the literature difficult or too much?
f		Experiment – when did you feel that you practiced and experimented in the course?
g		Teamwork – when did you work as a team? When did your group work with the other groups? (only used for ST3PRJ3)
h		Joker – what else did you experience?

Figure 3. The symbols are selected to make it easier to remember the meaning.



Figure 4. A learning path with posters

RESULTS

Results will be divided in two parts, the programming course and the CDIO-project course.

Programming course in 1. semester

The main themes in the evaluation on the programming course the first year (2010):

- Time. The students are stressed for different reasons, there are too many themes in the course, and they have not time enough to 'consume' it all. They find it is difficult to read what is expected from week to week, and they fell there is too much to learn.
- Reading. The book is difficult to read, and they cannot figure out what is important and what is not.
- Assignments. They learn a lot from the assignments and exercises and the pattern in the learning path shows that there are many stickers a (treasures) in connection with stickers f (experiments). They are kind of frustrated when they work on assignments in class because everybody wants the teachers help all the time.
- Concepts, some students explained the heavy workload and lack of clarity as a frustration because it is difficult to remember and understand all the new words and concepts.
- Clarity. During course students find learning targets difficult to understand.
- Learning. It is clear from the learning path, that students learn the most when they work with assignments and when they work hard and concentrated individually.

The learning path created is very useful as a starting point for reflections and discussions. Students discuss with other students and with teachers. The dialog is very important and gives much knowledge of the learning process for the students in the course. The course had been evaluated orally in the class half way through the course. Students said they didn't learn very much and they were frustrated and blamed the teacher, but the teacher got very little help to find out what to change.

The final results of the evaluation are some recommendations for the coming courses in programming.

Students ask for reading instructions, which can guide their reading of the book. The teacher comes up with the idea that students create their own kind of dictionary as a little assignment to every week through the course. The exercises can be divided into smaller assignments throughout the course. They should be very easy from a start and give the students motivation. The teachers try to implement the advice in the second semester courses for these students and also in first semester for coming students.

When this course is evaluated in 2011 the patterns are:

- Exercises and small assignments. They are very good. Test before examination was really good, more would be even better.
- Time. Students still find there is a time-pressure; there are still many themes and they spent a lot of time working with their homework.
- The dictionary. It is helpful but it takes a lot of time.
- Hard work. It is hard work to learn programming

The changes to the course made a huge difference. There is a discussion during the evaluation on how to encourage students to be more experimental and try to find out themselves what works and what doesn't in the exercises. Students are well aware that it takes hard work to learn programming. It also counts on the positive side this year that evaluation is after examination where most students got good grades and only a few failed, but it is obviously a result of the positive changes.

Everybody agree that it is important to keep high learning targets but the GUI-theme can be taken out and placed in a CDIO-project course.

DCIO-Project course in 3. semester

In this project the students are working on ECG signals in an open source system. Students are divided into groups and the groups have each their job to do, but in order to reach the learning targets in the project course they need to work together on some parts to make their systems communicate with each other.

The main themes in the evaluation on CDIO-project course (2010):

- Teamwork and dialog in the team. The students are experiencing a lot of problems in the teams regarding collaboration. This is generally a problem in this class. The good question is; how do we make good and well-functioning teams? How do we solve collaboration problems?
- New knowledge. Some of the students find it difficult to find the knowledge needed in the project. They would like more teaching/guidance in the unknown theory and technology.
- Unclear requirements from teachers. It is not clear to the students what the requirements are to the written report so they waste a lot of time discussing with each other and asking the teachers. They find learning targets unclear.
- Experiments and learning. Learning path shows that experiments and learning are closely connected. Students say that it's a very interesting project and a very close to reality-project. They have learned very much in this course.
- Communication between teams. There seems to be certain mistrust between teams, and teams don't want to help each other. Students want the teachers to

play a bigger role in facilitation collaboration between teams and to make teams for their next projects.

The most important issue in this evaluation is that all the problems with communication and collaboration between persons and between teams come to the open. This makes it clear to teachers that this group of students need help to manage team problems and that they need support in their next semester project.

When the evaluation is made in January 2011 themes are different

- Uncertainty about project. Students are uncertain on many things in the project; what different teachers expect and understanding learning targets. They find it impossible to reach the learning targets and that makes them very frustrated.
- They find the project very interesting and close to reality. They say they are too frustrated about many things but they have learned a lot
- Communication and collaboration within the teams function very well and also between teams. They have learned to collaborate and to find knowledge and use other people's knowledge.
- Experiments and data. Experiments and work on data are useful and connected to learning, but takes (too) long time. The progress in the project was too slow from the start.

This group of students find the project very difficult but they did actually very well in the final examinations, which took place before the evaluation. The students in this group have very high expectations to themselves and they work very hard to reach the ambitious goals. The evaluation gives valuable information on how and when the project should be presented for the students and the formulation of the learning targets. Like the first time this project-course was evaluated, the results give a lot of information on the group of students and how they learn and work together.

The evaluations of the CDIO-project course give very important information on how students experience that kind of team-work. The theme of the CDIO-project is great but teamwork is difficult. It shows how important it is to be aware of teams and to get involved as a teacher before problems affect the learning and outcome. But it is considered to be a very important part of the study to learn how to deal with team processes, problems and collaboration.

DISKUSSION

The purpose for this course evaluation is to enhance the students learning and to improve quality of the content and structure of the course. That calls for methods with focus on learning, cooperation between teacher and students, and structure in teaching [1]. The students are asked how they experience teaching and learning. It is important to distinguish between assessment and experience. The data from the students experience can be discussed and interpret by the teachers and students in the following process. The stickers on the path tell how the student experience. This is a qualitative method that gives a deep insight in how the participating students learn, how they understand and the data from the evaluation are in that respect subjective and derives from a few persons perspective [3]. It is difficult to synthesize and summarize the results [3], [4].

Would data be different if the six students were replaced with six other students? Yes, but the evaluation is very closely connected to the themes in the course and the students are reflecting and discussing, and in that process they agree on the main issues in the evaluation. It is believed that the issues would be almost the same in another group of students. The collected data are extensive and give the teacher useful information which obviously in the case with the programming course has had a positive impact.

The evaluation is an open dialog, were the teacher is present and that might hinder negative expressions from the students. On the other hand students show great responsibility and commitment and are very constructive. As students are involved in a dialog it is important that they agree to the summary presented to the class. It is difficult to engage students in evaluations if they don't see the results and even more difficult to engage them later on in future evaluations if the advises and discussions are overheard [2].

The first evaluations were guided by an external consultant who was also helpful in describing the evaluation method.

In 2011 the director of studies in Healthcare Technology has guided the evaluations. The close connection to teachers and to students is not considered to influence in a bad way. It is very important that there is trust and a good atmosphere, and that the teachers show that they want to listen and learn. As a process guide it is a difficult job to balance the themes and give everybody time to speak and it is also a difficult task to keep focus. Even though the visual result of the evaluation is a common reflection on the learning process, it is clear that the students also get important reflections on their individual learning process.

CONCLUSION

This kind of evaluation is very time consuming and is not intended to be used at the end of every course. But it is very useful in newly developed courses, in courses where other evaluations show discontent from students or where results are difficult to interpret. This was the case for the two courses evaluated.

The purpose was to test an evaluation method which would give the information needed to enhance student learning. This explorative evaluation method has this potential. The programming course is getting better and better, the students learn more and more, and they are less frustrated as is the teacher. The focus on how the learning processes and teaching is experienced and the dialog has been the key to understand what to do.

Regarding the project courses the most useful contribution is the information on how specific groups of students work and collaborate and therefore helps teachers to enhance guidance and performance for that group of students.

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WHY GET YOUR ENGINEERING PROGRAMME ACCREDITED?

Peter Goodhew

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ABSTRACT

In many countries engineering degree programmes can be submitted for accreditation by a professional body and/or graduate engineers can be certified or registered. Where this is available most academic institutions feel that they must offer accredited engineering programmes. I suggest that these processes are at best ineffective (they do not achieve their aims) and at worst they are destructive of creativity, innovation and confidence in the academic community. I argue that such processes (including any internal certification within CDIO) should be abandoned completely. I propose alternative ways of maintaining the quality of engineering design and manufacture, which place the responsibility where it properly lies – with the manufacturer or contractor. This is a polemic piece, not a referenced review of accreditation.

KEYWORDS

Accreditation, registration, certification, professional bodies.

THE CASE AGAINST ACCREDITATION

In many countries undergraduate engineering programmes can be submitted to a national body for “accreditation”. Graduates from accredited programmes are eligible, often with an additional requirement for relevant work experience, for registration as a professional engineer. In the UK this accreditation is overseen by the Engineering Council via UK-Spec and opens the way to C.Eng, I.Eng or Eng Tech qualifications. In the USA ABET serves a similar function, while in Australia the appropriate body is Engineers Australia. In all cases the programme, its students, and sometimes its graduates, are scrutinised by a committee of professional engineers before accreditation is awarded for a fixed period such as five years. The accreditation process involves substantial paperwork and usually a one or two day visitation, so is quite costly both for the educational institution and the professional body. I argue in this paper that this considerable effort does not represent good value for money and in some cases may have a negative effect on the quality of engineering education.

Did the accreditation of professional engineering programmes prevent the disastrous crash of the Airbus 330, flight AF 447, in June 2009? Equally, is it responsible for the fact that the Eiffel tower has remained standing for 120 years? Or that my iPhone is so brilliant? No, no and no. So what is accreditation supposed to be for? At the highest level I presume that the intention is to ensure and enhance the quality and safety of engineered products throughout the world. At a more mundane (and self-interested) national level it might be intended to enable the world-wide transferability, and thus profitability, of a nation’s engineering industry by ensuring the international credibility and employability of its engineers.

These seem to be laudable objectives, but delivery of them is several steps away from the accreditation of university programmes. The logic is presumably that the employers of

professional engineers must have confidence, via external testimony, in their skills and their fitness to practice. This confidence is engendered by their status as professional (*chartered* in UK parlance, *registered* in other jurisdictions) engineers, part of the qualification for which is that, at some time in the past, they graduated from an “accredited” degree programme. These engineers also have to demonstrate some appropriate experience in employment and the membership of a professional body.

I find the whole system of accreditation unsatisfactory in two ways: It does not deliver the intended outcome (and so is ineffectual) and, additionally, it can damage our education system and thus our students and graduates.

First, the charge that it is ineffectual: Engineered products are conceived, designed, made and operated (CDIO-ed) by engineers employed by large or small companies. Some, but certainly not all, of these engineers may be chartered. They will usually have earned their chartered status by virtue of the work undertaken in their first few years of employment, backed up by the degree they were awarded several years ago. Since receiving their chartered status they will have been encouraged to undertake continuous professional development, but this will not have been checked. A fifty-year-old chartered engineer is thus operating on the basis of a validation process twenty years ago and a degree awarded about 25 to 30 years ago. The accreditation of this degree, so long ago, has almost no relevance for the engineering practices in use today. Indeed if the degree was typical of those awarded 25 years ago it will have contained a significant amount of engineering science and very few tests of engineering aptitude or attitude. (Which is of course why we have the CDIO movement.) The fitness to practice of an individual engineer will in reality depend on what they have done, seen and learned during their working life, which is almost independent of the content of their first degree. Indeed the technical content of a degree in one engineering discipline may have almost no overlap with the content of another engineering discipline so it is hard to argue that subject content has anything to do with being, or thinking like, an engineer.

Furthermore an engineer employed today may be working in an area unrelated to their original area of study. This is very likely for bioengineers, nanoengineers, environmental engineers, nuclear engineers and others working in interdisciplinary areas. Their original degree would either have been un-accredited or the accreditation would relate to a different disciplinary area. How can this in any way validate or assure the quality of their current work?

A third issue is the effectiveness of the quality assurance provided by chartered status. I have already asserted that there are almost no checks on the continued professional development of chartered engineers, but equally there are almost no cases of the de-registration of rogue chartered engineers (and even if there were, they would certainly – like doctors – be de-registered after they had committed a grave misjudgement or offence, not before!).

So the accreditation of programmes is certainly ineffectual, but it is also damaging to the education process. University departments of Engineering spend a great deal of time preparing for accreditation visits, and tuning their degree programmes to fit the perceived requirements of their professional bodies. They do this not to improve their programmes (most programme leaders do not believe that the comments of accreditors will achieve this) but because of the fear that they will no longer be able to compete in the marketplace for students if they are not accredited. This fear is probably misplaced, but no department has the courage to put it to the test! Accreditation panels almost always feel that they should make some critical (framed as “helpful”) comments but these usually reflect the prejudices of individual panel members, who are rarely experts in higher education and frequently elderly and tending to be out of date. [I have resolved never to accept another invitation to sit on an accreditation panel now I have

reached 65.] The damage to the system is that the threat of accreditation makes our engineering departments more conservative, less willing to change or innovate, as well as taking time and money which would be better spent on the education of their students. It also reinforces (unhelpfully) the audit culture which has over-run our universities in the last twenty years (at least in the UK).

It would be unreasonable to criticise the existing system of accreditation without making some attempt to suggest what might replace it to provide the assurance of quality demanded by society. My suggestion is that the responsibility for the safety and quality of products (from multi-billion tunnels to five-penny toys) should remain where it legally is – with the manufacturer or major contractor. These businesses should assure themselves that their workers are appropriately skilled and work to appropriate safety and ethical standards. To achieve this they might need to strengthen their recruitment procedures to include a real assessment of candidates' current abilities and skill sets. They would also want, as many do, to ensure periodically that their employees are up to date. They might wish to buy in the necessary training expertise, perhaps even from a local university, but they will not be much helped by a past "accreditation". The proof of the quality of training, and of initial education, will be demonstrated by the performance of the employee – supervised and checked by experienced colleagues – not by their possession of a yellowing piece of paper.

I notice that I have not mentioned professional bodies. What might their role be? Certainly not as accreditors, but perhaps as honest brokers between employers and trainers and educators, or as forums for discussion (but not regulation) of best practice. In which case perhaps there should be an upper age limit for service on any committee or as an officer – shall we say 50 – and those in their dotage (like me) should only speak when asked.

The arguments I have advanced here also apply to the certification of undergraduate programmes as (for example) "CDIO-compliant". Such a scheme would cost effort (and almost certainly money) to implement, it would cost even more to police (so this would be unlikely to happen) and would still offer no assurance of the quality of a engineering graduate. A further particular argument which applies to CDIO members is that (unlike many other engineering teaching departments) they have already shown their commitment to improving engineering education and are thus the least likely programmes to need the additional discipline offered by certification process. So I strongly suggest that we do not bother.

BIOGRAPHICAL INFORMATION

Peter Goodhew is Emeritus Professor in the School of Engineering, University of Liverpool, UK. He is one of the Directors of CDIO and the joint Leader of the UK & Ireland region. He is interested in many aspects of engineering education and has recently published a short book on the subject: "Teaching Engineering", downloadable from <http://www.materials.ac.uk/resources/Teaching-Engineering.pdf>

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Using CDIO to Meet Accreditation Expectations at The University of Sydney

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ABSTRACT

This paper discusses our experience in the School of Electrical and Information Engineering (EIE) at the University of Sydney in successfully using the CDIO framework to help meet Accreditation expectations in preparation for our 2009 accreditation visit. We review the generic graduate attributes and the competency standards of the Australian accreditation body, Engineers Australia (EA), and discuss how we mapped them to the CDIO framework. We analyse the recommendations from the 2004 accreditation visit and compare the 2004 and 2009 visit outcomes, with the 2009 visit report noting that the adoption of CDIO had resulted in a more holistic approach to our program educational design and better quality control over them.

KEYWORDS

Program design, accreditation, quality control, CDIO standards.

INTRODUCTION

This paper addresses a key issue of direct concern to the CDIO constituency, namely the relationship between CDIO and accreditation, and discusses our experience in the School of Electrical and Information Engineering (EIE) at the University of Sydney (USyd) in successfully using the CDIO framework to help meet Australian Accreditation expectations in preparation for our 2009 accreditation visit.

The previous accreditation visit in 2004 raised particular issues regarding the teaching of design, project management, business and management, broad context problem solving, systematic re-enforcement of generic capabilities throughout the curriculum and quality control of the programs. The 2004 visit team strongly advocated that the School take a more holistic approach to educational design.

Over the five years between the 2004 and 2009 accreditation visits, the School of EIE adopted the CDIO framework as the context for its education. The programs were extensively revised using the CDIO standards and syllabus as guides. A careful mapping was carried out between the CDIO standards and syllabus, the EA generic graduate attributes and competency standards and the University of Sydney's graduate attributes. This mapping provided a foundation for the submission for the 2009 visit. This paper discusses in detail how the issues raised during the 2004 visit were dealt with.

The outcomes of the 2009 visit were far more satisfactory than the 2004 visit, with plaudits from the visit team for the way in which the School had adopted CDIO and used it to renovate its programs.

IDENTIFYING THE NEED

Before adopting CDIO as the context within which the School of EIE would renovate its curricula, we had to clearly identify the need to do so along with the expected benefits, in order to motivate the senior management (the Dean) as well as the academic staff of the School that the undertaking was worthwhile.

In 2004, the School offered a set of five programs, namely Computer, Electrical, Power, Software and Telecommunications Engineering. All are standard four-year engineering programs, share common core subjects, and all could be combined with Commerce, Science, Arts, Medical Science or Law programs, which would earn the student two degrees in 5 years (6 for Law). This resulted in a flexible set of programs, with over 30 electives, offering students a wide choice and the ability to shape their programs to their personal taste.

The goals of the programs were to produce graduates that are equipped with the generic skills we expect of all our graduates, and to provide

- Fundamentals of sciences, technologies and engineering.
- Fundamentals of technical area plus some specialisation
- Opportunities to specialise or generalise through a wide choice of electives
- Complete a major thesis project

At Sydney, in common with many Universities, student surveys of the programs are carried out every semester, both for individual courses (Unit of Study Evaluation, or USE) and surveys of recent graduates to assess their overall satisfaction with the programs (Course Experience Questionnaire (CEQ), since 2010 incorporated into the Australian Graduate Survey (AGS)). Unfortunately, in 2004, our survey scores were falling. Analysis of the freeform comments in surveys found that the problems were

- Conventional curriculum
- Lots of Maths, Physics, programming, but little engineering in first 2 years
- Little overview of the disciplines
- Little experience of what it “means to be an Engineer”
- Not enough design or project work
- Little experience of industry or of manufacturing process
- Unexciting and uninspiring, not attractive

Essentially, we were losing the interest and excitement of the students in the first two years of the programs.

2004 ACCREDITATION VISIT

The 2004 Accreditation visit to our School helped us to crystallise our views of the need to renovate our programs. The visit team report identified the need for

- An holistic approach to curriculum design
- An improved program quality system
- Imparting the full range of generic attributes to our students
- Creating a “forward looking approach” to teaching
- Developing better, more consistent approaches to team project work
- Renovating our laboratories to better support team project work.
- Developing better assessment practices

- A stronger approach to design
- Introducing a first year introduction to engineering unit

In order to respond effectively to these requirements, a search was undertaken to evaluate learning and teaching frameworks in engineering which led to CDIO, which appeared to offer all of the above in a framework of international best practice in engineering education. Prof E Crawley was then invited to visit the School and present a case for the merits of adopting CDIO, which the School then did in 2006.

PREPARING FOR ACCREDITATION

In preparing to use the CDIO framework for the 2009 Accreditation Visit, we identified the need to:

- Map CDIO attributes, USyd GAs to EA GAs
- Map USyd unit and program outcomes to CDIO syllabus and EA Competencies
- Show consistent, holistic program design
- Show a high level of involvement with Industry
- Show first rate design and team project work
- Show effective quality control
- Develop strong involvement and enthusiasm of staff and students

The Accreditation Body for Engineering in Australia is Engineers Australia (EA) visits each accredited institution every five years. At the time of the 2009 visit, EA's published criteria for accreditation were the National Generic Competency Standards (NGCS) [1]. Accredited bodies were expected to show that they met these standards. The standards feature three main domains of competency, namely;

- Knowledge Base, which relates to all the fundamental and technical knowledge;
- Engineering Ability, which addresses problem solving techniques, responsibilities of engineers, project design issues and business principles; and
- Professional Attitudes, which includes elements of effective communication, team work, ethical responsibilities and other professional attitudes.

Each domain articulates to several sub-domains and these are similar in content and meaning to the CDIO syllabus, but there are also instances where the two differ.

Most Universities also have their own graduate attributes (GAs) as does the University of Sydney. While for accreditation EA's NGCS was critical, for our program design we wished to show correspondence between the CDIO syllabus, USyd's GAs and the NGCS. To achieve this, a complete mapping was carried out and is shown in summary form in Appendix A. Further details can be found in [3]. Each teaching module (Unit of Study (UoS) in USyd's parlance) was checked against this map and a fully detailed evaluation of the curriculum was carried out so that we could be sure that requirements of the NGCS were satisfied. The objective was to show convincingly to the visit team that the School graduates engineers who are skilled in their chosen area of technology while having a high level of personal and interpersonal skills, are capable of working effectively individually and in teams to conceive, design and implement modern engineering artefacts and systems.

The use of the CDIO reference syllabus also provides benchmarking against other Universities internationally allowing us to show that our programs meet the targeted graduate capabilities and in particular, address the projected levels of technical competence, enabling knowledge and skills, engineering application skills as well as personal and professional skills that EA requires we instil in our graduates. In EIE, we achieve these outcomes by applying the engineering problem solving paradigm, by first developing a sound understanding of the fundamental skills needed by contemporary engineer in order to be able

to develop complex artefacts and systems. This is accompanied by a focus on the personal and professional skills central to engineering practice. We follow this by honing those skills in the 3rd and 4th year through industry-relevant team projects, carried out in the context of the specialist units of study and culminating with the capstone thesis project. Throughout, our curricula seek to endow our students with a mastery of the fundamentals of the appropriate technical knowledge and reasoning by continuously strengthening their knowledge in the context of their team project work. In order to work effectively in teams, students must develop the interpersonal skills of teamwork and communications. Finally, the curricula, by emphasizing team-based projects, give the students confidence in their ability to create products and systems. At all times the relevance to industry practice is emphasized, through industry involvement in projects and use of external lecturers and supervisors. Further detail on recent work regarding the teaching Engineering Design in Australia, carried out for the Australian Learning and Teaching Council and which recognises the impact of CDIO may be found in [5].

Our laboratories were extensively renovated, using the CDIO standards and experience from MIT, Linköping and Liverpool as guides, with thanks for their assistance. The Laboratories were refocused on Active Learning, supporting a variety of learning modes through flexible spaces to enhance interactive and group learning. The new integrated learning spaces were the first of their kind in the University. The Power Engineering laboratory in particular enables students to work on standard industrial equipment as opposed to computer simulations, thereby closing the gap between theory and real world practice, providing a combination of a professional engineering environment and curriculum, integrating advanced methods of teaching and learning activities that resemble professional industrial practices and involves considerable input from industry at every step. The lab was developed by Prof V Agilides [2] and follows a similar design implemented by him at Murdoch University. We are very fortunate at the University of Sydney to have many industrial partners supporting this vision. Selected labs are open for extended hours during the semester to allow students to work on their projects at hours convenient to themselves.

The revised programs and mappings were presented to Engineers Australia in the submission for the 2009 visit.

OUTCOMES OF THE 2009 VISIT

The visit panel reported that it was “pleased to note the many actions that had been initiated in response to the recommendations of the 2004 panel” and further noted the School’s improved quality management system, the redevelopment of laboratories to provide a more collaborative, project based learning experience and that “the CDIO initiative will drive a strong project based learning focus and maintain an emphasis on tracking engineering design capability development”. The board further noted that “generic capabilities development is a mandated component of the CDIO standard and this will provide the framework for a more systematic approach” and that the new first year ‘Professional Engineering and IT’ unit provides a “foundation awareness and commitment to aspects of sustainability and professional ethics, and also builds a foundation understanding of professional engineering practice”.

The panel noted with approval that the detailed mapping table demonstrates how the graduate attributes map to the Engineers Australia Generic Attributes and to the NGCS and further noted that the adoption of the CDIO framework and the School’s involvement as a collaborating institution within the CDIO Consortium significantly influenced improvements in the quality of the School’s teaching programs. The panel commended the School’s engagement with the CDIO Consortium as “worthy of consideration from a Faculty wide perspective”.

CONCLUSIONS

The School of EIE's adoption of CDIO has led to the strengthening of the School's programs and improvements in the assessment of the School at the most recent accreditation visit. Considerable effort was required to map the requirements of the accreditation body, the CDIO syllabus and the School's programs. This was undertaken as part of the program revision, and proved valuable in presenting the School's position in a coherent and holistic way to the Accreditation Panel.

It is also worth noting that the increasing takeup of CDIO in Australia, with 12 Universities now using CDIO to some degree, has had an influence on the Accreditation body. A recent review of engineering education in Australia by King [4], undertaken on behalf of the Australian Council of Engineering Deans, along with the experience gleaned from many accreditation visits, has led Engineers Australia to revise the NGCS [6]. The CDIO standards are currently also being updated. As a result of these dynamics, we will soon revise our mappings in order to stay current and be up to date at the next accreditation visit in 2014.

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Appendix A: Graduate Attribute and Engineers Australia Competency Standards Mappings

Graduate Attributes Comparison			Competency Standards Comparison			
USYD graduate attributes	ENG-IT graduate attributes (Aug 08)	EA graduate attributes (generic)	EA program structure elements	EA Stage 1 Competency Standards – Level 2	CDIO Standards – Level 2	CDIO Standards – Level 1
Personal & Intellectual Autonomy	Discipline Expertise	⇒ In-depth technical competence in at least one engineering discipline.	Engineering discipline specialisation	PE1.2 In-depth technical competence in at least one engineering discipline PE1.3 Techniques and resources	1.2 Core engineering fundamental knowledge. // PE 1.2 – R 3 1.3 Advanced engineering fundamental knowledge. // Unique PE 1.2 2.1 Engineering reasoning and problem solving. // PE 1.3 2.2 Experimentation and knowledge discovery. // PE 1.3 – R 5 2.5 Professional skills and attitudes. // PE 1.2 4.3 Conceiving and engineering systems. // PE 1.3	1 – TECHNICAL KNOWLEDGE AND REASONING. // R 2 2 - PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES. // R 3 4 - CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND NATURAL CONTEXT. // R 1
	Science & Engineering Fundamentals	⇒ Ability to apply knowledge of science and engineering fundamentals.	Mathematics, science, engineering principles, skills & tools (inc. computing, experimentation).	PE1.1 Knowledge of science and engineering fundamentals	1.1 Knowledge of underlying sciences. // PE 1.1 – R 2	1 - TECHNICAL KNOWLEDGE AND REASONING. // UNIQUE R 1
Information Literacy	Information Skills	⇒ Expectation of the need to undertake lifelong learning and the capacity to do so.	Mathematics, science, engineering principles, skills & tools (inc. computing, experimentation).	PE3.2 Ability to manage information and documentation PE3.6 Capacity for lifelong learning and professional development	2.2 Experimentation and knowledge discovery. // PE 3.2 2.4 Creative and critical thinking, educating and aesthetics. // PE 3.6 – R 2 2.5 Professional skills and attitudes. // PE 3.6 3.1 Teamwork. // PE 3.6 3.2 Structured communications. // PE 3.2 – R 3	2 - PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES. // R 3 3 - INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION. // R 2
Communication	Communication	⇒ Ability to communicate effectively, with the engineering team and with the community at large		PE3.1 Ability to communicate effectively, with the engineering team and with the community at large	3.1 Teamwork. // PE 3.1 – R 2 3.2 Structured communications. // PE 3.1 – R 4	3 - INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION. // R 2

Graduate Attributes Comparison				Competency Standards Comparison			
USYD graduate attributes	ENG-IT graduate attributes (Aug 08)	EA graduate attributes (generic)	EA program structure elements	EA Stage 1 Competency Standards – Level 2	CDIO Standards - Level 2	CDIO Standards – Level 1	
Research & Inquiry	Design & Problem Solving	<p>⇒ Ability to undertake problem identification, formulation, and solution</p> <p>⇒ Ability to utilise a systems approach to design and operational performance</p>	Engineering design & projects	<p>PE2.1 Ability to undertake problem identification, formulation, and solution</p> <p>PE2.3 Ability to utilise a systems approach to complex problems and to design and operational performance</p> <p>PE2.4 Proficiency in engineering design</p> <p>PE3.3 Capacity for creativity and innovatio006E</p>	<p>2.1 Engineering reasoning and problem solving. // PE 2.1, PE 2.4 – R 2</p> <p>2.2 Experimentation and knowledge discovery. // PE 3.3</p> <p>2.3 System thinking. // PE 2.1, PE 2.3 – R 2</p> <p>2.4 Creative and critical thinking. // PE 2.3, PE 3.3 – R2</p> <p>2.5 Professional skills and attributes. // PE 2.4</p> <p>2.6 Leadership: character and core personal values. // PE 3.3</p> <p>4.1 External, societal and natural context and environment. // PE 2.4</p> <p>4.3 Conceiving and engineering systems. // PE 2.4 – R 4</p> <p>4.4 Designing. // PE 2.4 – R 6, PE 2.3 – R 2</p> <p>4.6 Operating. // PE 2.3 – R 3</p> <p>4.7 Engineering entrepreneurship. // PE 2.4</p> <p>4.8 Leading engineering endeavours. // PE 3.3 – R 2</p>	<p>2 - PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES. // R 6</p> <p>4 - CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND NATURAL CONTEXT. // R 6</p>	
	Teamwork & Project Management	<p>⇒ Ability to function effectively as an individual and in multidisciplinary and multicultural teams, as a team leader or manager as well as an effective team member</p>	Engineering design & projects	<p>PE2.5 Ability to conduct an engineering project</p> <p>PE3.5 Ability to function effectively as an individual and in multidisciplinary and multicultural teams, as a team leader or manager as well as an effective team member</p>	<p>2.5 Professional skills and attitudes. PE 3.5</p> <p>2.6 Leadership: character and core personal values. // PE 3.5 – R 2</p> <p>3.1 Teamwork. // PE 3.5 – R 4</p> <p>3.2 Structured communication. // PE 2.5</p> <p>3.4 Leadership: relating to others. // Unique PE 3.5</p> <p>4.3 Conceiving and engineering systems. // PE 2.5 – R 2</p> <p>4.8 Leading engineering endeavours. // PE 2.5 – R 2</p>	<p>2 - PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES. // R 2</p> <p>3 – INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION. // R 3</p> <p>4 - CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND NATURAL CONTEXT. // R 2</p>	

Graduate Attributes Comparison			Competency Standards Comparison		
USYD graduate attributes	ENG-IT graduate attributes (Aug 08)	EA graduate attributes (generic)	EA program structure elements	EA Stage 1 Competency Standards – Level 2	CDIO Standards – Level 1
Ethical, Social & Professional Understanding	Professional Practice	⇒ Understanding of the social, cultural, global, and environmental responsibilities of the professional engineer and the need for sustainable development ⇒ Understanding of the principles of sustainable design & development ⇒ Understanding of professional and ethical responsibilities, and commitment to them	Exposure to Professional Practice	PE1.4 General Knowledge PE2.2 Understanding of social, cultural, global, and environmental responsibilities and the need to employ principles of sustainable development PE2.6 Understanding of the business environment PE3.4 Understanding of professional and ethical responsibilities, and commitment to them PE3.7 Professional Attitudes	2 - PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES. // R 5 4 - CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND NATURAL CONTEXT. // R 6
				2.1 Engineering reasoning and problem solving. // PE 2.6 + PE 3.7 2.2 Experimentation and knowledge discovery. PE 1.4 2.4 Creative and critical thinking, educating and aesthetics. PE 3.7 2.5 Professional skills and attitudes. PE 3.7 2.6 Leadership: character and core personal values. // PE 2.2 + PE 3.4 + PE 3.7 4.1 External, societal, and natural context and environment. // PE 2.2 – R 3, PE 3.4 – R 2 4.2 Enterprise and business context and environment. // PE 2.6 – R 2 4.3 Conceiving and engineering systems. // PE 2.6 – R 2 4.4 Designing. // PE 2.2 – R 2 4.7 Engineering entrepreneurship. PE 2.6 4.8 Leading engineering endeavours. PE 3.7	
Col 1	Col 2	Col 3	Col 4:	Col 5:	Col 6:
			Accreditation Manual Doc. P02 Item 5.2	Accreditation Manual Doc. P05 Item 4	CDIO Level 2 mapping column based on mapping work done by Alici Popp. Done second pass and added unique link weighting consideration.
					CDIO Level 1 based on mapping work done by Alici Popp. Ranking based on CDIO Level X.X in this document.

Notes:

- For column 6, items which are written in grey colour are considered to have less weight with respect to the mapping developed. Information posted after the '//' double forward slash indicates explicitly the items being mapped. The 'R - #' indicates the rank. The higher the rank the stronger the link. Unique results are given a higher weight in the ranking.
- Column 7 is the corresponding level 1 items based on aggregation counts from the level 2 items.

A real CDIO mechanical engineering project in 4th semester

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ABSTRACT

In the past 6 years at the mechanical engineering study at the Engineering College of Aarhus we have been practicing project work on 4th Semester in the design of energy technology systems. In my presentation, I will give a description of the project, and the thoughts behind; pedagogic-didactic as well as technical and professional considerations. The project is presently a permanent part of the 4th semester and counts as one third of the semester. The semester's theme is Energy-and System Design. Content on 4th semester is organized in light of which skills an engineer must possess in the field of energy technology. Here, it is vitally important, that the engineer is able to develop energy technology systems, thus being able to design systems, and not just individual components. It is not sufficient, that the engineer is able to calculate eg. a heat exchanger; the engineer must be able to consider the components as parts of a complex system. The semester project design is developed on basis of these considerations.

The semester consists of 4 theory courses in: thermodynamics, control- and simulation of dynamic systems, electronics and hydraulic systems. The project work is performed in groups of 4-6 students, and will partly support the general theory being taught in the courses, but will also provide students with skills in teamwork, project work and system building. The pedagogical considerations behind the development of the project are quite simply that students learn best through active work and experiments, after which they can analyze and reflect on the results obtained. It was therefore natural to enable the students to implement projects based on the ideas in the CDIO concept.

KEYWORDS

Energy and system design, prototypes, project work, thermodynamic, control-and simulation of dynamic systems.

INTRODUCTION

In the following, my intention is, to describe the practical implementation of several key CDIO elements through a 4th semester project at the mechanical department at Engineering College of Aarhus. The semester's theme is Energy-and System Design. Content on 4th semester is organized in light of what skills an engineer must possess in the field of energy technology.

The most important key CDIO elements implemented in the project are:

- **Standard 2, CDIO Syllabus Outcomes, section 2, 3 and 4**
 - o Section 2 (*Personal learning outcomes*). The current project focuses specifically on problem solving, experimentation and knowledge discovery,

system thinking and creative thinking. The project is specifically working with the development of energy technology systems based on real problems.

- Section 3 (*Interpersonal learning outcomes*). The current project focuses on individual and group interactions, as the work is done in groups of 4 - 6 students.
- Section 4 (*Product and system building skills*). This element fits exactly with the current project, as most of the projects are done in cooperation with companies near Aarhus.

- **Standard 3, Integrated Curriculum**

This standard is described in the following manner; *A CDIO curriculum includes learning experiences that lead to the acquisition of personal, interpersonal, and product and system building skills integrated with the learning of disciplinary content...*

This standard is incorporated in the project, as the project work is done parallel to 4 theory courses in: thermodynamics, control- and simulation of dynamic systems, electronics and hydraulic systems, and will partly support the general theory being taught in these courses, but will also provide students with skills in teamwork, project work and system building.

- **Standard 8, Active Learning**

Active Learning Teaching and learning based on active experimental learning methods is the pedagogical thinking behind the design of the course.

PEDAGOGICAL AND DIDACTIC CONSIDERATIONS

The pedagogical considerations behind the development of the project are quite simply, that students learn best through active work and experiments, after which they can analyze and reflect on the results obtained. Three basic elements have to be present to ensure that learning takes place, 1) the student must work, 2) work engaged and 3) and the work must be within his/her possible bandwidth [1]. This I think we have fulfilled here! The students work both practically and theoretically with important issues, they work engaged, because they have chosen relevant and motivating topics and they work within their capable bandwidth because they more or less decide themselves how deep they dive into the theory.

Based on this it was therefore natural to us, to enable the students to implement projects based on the ideas in the CDIO concept.

The whole way through the design of the project course we were aware, that the students to as far extent as possible have to work the same way in the project work as they will do when they have graduated with an bachelor degree in engineering. Therefore we try as much as possible to encourage the students to find real problems to solve together with a company, even though this is sometimes in conflicts with the content, we also want the students to learn during the course.

The students are to find and describe the project problem by themselves and afterwards to have the description approved by their supervisor. With the approval procedure we want to ensure that the project has the right focus namely, to design an energy technical system and to do all relevant calculations needed (specific thermodynamic and simulation considerations).

To ensure the integrated curriculum, we have designed a scheme for the entire semester, where courses are planned parallel to the project course. It is done parallel to 4 theory courses in: thermodynamics, control- and simulation of dynamic systems, electronics and hydraulic systems, and will partly support the general theory being taught in these courses, but will also provide students with skills in teamwork, project work and system building.

Thermodynamic, 7½ ECTS
Control- and simulation of dynamic systems, 5 ECTS
Electronics, 5 ECTS
Hydraulic systems, 2½ ECTS
Project work course, 10 ECTS

Figure 1. Scheme for 4th semester in mechanical engineering

LEARNING OBJECTIVES OF THE PROJECT COURSE

The learning objective of this fourth semester project reads:

When the semester project is completed, the student will be able to:

- Design, analyze and calculate an energy technical system, specifically in terms of thermodynamic calculation.
- Select and explain the choice of instrumentation
- Analyze the structure of the system in order to be able to simulate the system function and select the appropriate regulating components
- Develop a prototype and test it in the laboratory
- Write a technical report incl. references and experimental report

Project work has to include an experimental part, ie. test of a prototype, and it is important that the measurements are compared with the calculation model or the base calculations and that conclusions are made according to this.

CONTENTS AND IDEAS OF THE PROJECT DESIGN

Based on the above mentioned considerations, we designed a project work, as follows.

- There will be a short start-up meeting where:
 - o Groups are formed by students of 4 to 6 people. The groups are formed based on the students' own preferences, although we encourage them to form groups based on which skills are needed in this specific project work.
 - o Project ideas are presented. We have a project catalogue with ideas to inspire the groups to find a motivating project and we also have a list of relevant companies to contact, but as earlier mentioned, they are free to find a project and a partner company on their own.
 - o Learning objectives, level of implementation, guidance form and evaluation form are presented.

- A main idea behind the project work is, that students must develop an energy-technical system, buy parts and components and build them together into a prototype. Students thereby gain experience with putting the related courses in perspective and they learn actively by using the theory on "real" issues.
- The projects are open, i.e. the task text is not fixed. The students are required to work seriously with the problem formulation and specification. The phases of the project implement elements that the students have worked with at the previous semesters. The students are allowed to present their own project ideas, they can find a project from a company or they can choose a project from the project catalogue. In all cases, they must have the project formulation approved by the teachers.

As a part of the project work the groups must hand in a project specification which has to be continuously and regularly updated and at all times in the the project period has to be available. It is important that the project specification is so detailed a technical description of the project, that the supervisors on this basis can decide whether the project meets the learning objectives and professional themes on fourth semester.

The idea behind this demand is, that this also is how engineers often works with projects in real life and that it is important for the students to develop professional communication skills.

The project specification has to contain:

- o A cover page with title of project, version number and date
 - o A section titled "Project". This section includes text, figures, etc. This has to be a detailed description of what the project is all about. It should enable an outsider to get a fairly overview, and it should enable the supervisor to assess, whether the project can meet the learning objectives.
 - o A section entitled "Timetable". Here one should be able to see the timetable for the project, i.e., applicable to the already time already spent and a plan for the remaining time.
 - o A section with information on project staff, i.e., names, initials, telephone numbers etc.
 - o Optionally also a section on with project group cooperation and other issues.
- Examples of projects that have been implemented:
 - o Dehumidifier
 - o Soft ice machine
 - o Milk Shake machine
 - o Desalination plant
 - o Climatic chamber
 - o Heat pump
 - o Water Cooler

PHASES OF THE PROJECT WORK

When designing the project course, we have tried to fulfil the CDIO-phases as much as possible, not only to fill out a kind of form or table but because it makes sense since this is how engineers work.

The course design is a result of some years of development. The challenges in this development process have been many. To mention some:

- Being able to build the many prototypes (normally 5- 8 per semester) it requires good machine shop with sufficient workers, tools and last but not least a stock with the relevant goods and articles

- It is resource consuming to build the prototypes, in terms of salary to the workers and purchasing of all the components
- it requires the availability of many group rooms for the students to work without being interrupted and for the students to be able to lock their rooms, so that they can use them as a place where small experiments can be made
- it has required some development of skills among the staff to be able to give the appropriate supervision
- it is important, that the supervisors have broad competences in the field of thermodynamic systems and simulation of dynamic systems etc., since the students come up with very different and creative ideas. Since we have a limited staff in this area and often have to hire some supervisors on hourly basis, it is a challenge to find supervisors who are competent in this field

Below, description of the phases as the structure is just now:

1. First phase of the project is to establish project formulation, and from a brainstorming session to come up with possible solutions. This is the conceptual clarification phase, the **conceiving phase**. In this phase the students use the project work tools that they have required in the previous semesters, such as tools for brainstorming and problem solving.
2. Second phase is the **design phase**, which most of the time takes place in the group rooms, complemented by small experiments in laboratories, group room and the machine shop.
3. The third phase is the construction of prototypes, the **implementation phase**. Here, the students work in groups in the machine shop, with help from the technical staff.
4. The fourth phase is the testing phase, where students perform function tests and measurements on the prototype, the **operating phase**. This phase should, according to the CDIO standards, take place in real-life situations. This has in most projects not been possible to fulfill, because of time resources etc.
5. The final phase is the **documentation phase**, where a technical report is produced, that describes all four phases and explain the group's calculations, the design process, analysis and comparisons between test results and calculations. The report shall also include reflections on the group's work process.

The students will at the examination present their results and the project is evaluated in the light of the report and an individual examination.

REFLECTIONS AND CHALLENGES

We have now been working with this project design in more than 6 years and have constantly been developing the design. Still there are a lot of things to do, things to improve and challenges to meet.

Hereby I have listed some of the challenges, I see, and some reflections on how the design works:

- When the students work in groups, they develop some important skills, such as interpersonal, teamwork, leadership, and communication skills, but in their future career they in many cases will have to work partly alone. Although they work in teams

they partly will have to work out individual problems in the role of an expert. These competences are not developed sufficiently in the project work.

- Testing of the prototype has to evaluate specific calculations and assumptions. This work is not done in a sufficiently scientific and systematic way. It does not give validated and reliable results.
- The reflections on the project work are not satisfactory. The students do not sufficiently reflect and compare the calculations and the test results. Here they maybe miss some tools.
- When building the prototype, the students do a lot of ordinary handwork, because they think it is fun and because of lack in workers in the machine shop. Handwork is not a learning objective. Although it also is motivating and fun, we have to be aware of the balance here.
- The process of forming the groups is not optimal. Here we have to look at other solutions. Maybe forming the groups according to the competences represented in the groups or similar.

CONCLUSIONS

When asking, is this project design a success? I have to say; yes. I think so.

Let me justify this in the following.

What was the goal and did we reach it?

The reason, why we chose this design, can be read from the learning objectives. This is what we want the students to learn. So, let us take a look at those:

- *Design, analyze and calculate an energy technical system, in terms of thermodynamic calculation specifically.* We have not comparable data that shows if the students learn more from this than from other possible designs. But we observe that the students are working actively and hard on the projects and with designing, analyzing and calculating so we strongly believe that the students learn through the projects.
- *Select and explain the choice of instrumentation.* The project work force the students to choose proper instruments, and if they fail, they will have inappropriate results.
- *Analyze the structure of the system to be able to simulate the system function and select the appropriate regulating components.* Here we see the need of some improvements. The students have problems with making proper mathematical models as basis for the simulations.
- *Develop a prototype and test it in the laboratory.* We see a lot of amazing prototypes and think that it is incredible what the groups reach in relatively short time. In terms of the test, as mentioned above, here we see some improvement needed.
- *Writing technical report incl. references and experimental report.* The students do write proper reports, but again here we see some improvement needed.

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Teaching chemical product design to engineering students: course contents and challenges

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ABSTRACT

Chemical product design is not taught in the same way as traditional engineering courses like unit operations or transport phenomena. This paper gives an overview of the challenges that we, as teachers, have faced when teaching chemical product design to engineering students. Specific course contents and relevant teaching methods are discussed.

Introduction

The master course Chemical and Biochemical Product Design has been taught to engineering students at DTU for the past 10 years. The course covers the main phases of product design from mapping of customer needs, over idea generation and selection, to product development. Details of this approach are available in text books on the topic [1,2]. The primary aim of the course is to provide the students with a quantitative approach that enables them to analyse products and ideas using fundamental scientific disciplines from the engineering curriculum. The course is comprised of four team projects of which the last one (60% of the work load) is dedicated to the student teams own identified needs. Examples of needs that students have worked on are solvent-free nail polish, fast cleaning of baby bottles, new ways to anti-icing on cars, slow-melting ice cream, and coffee tablets for instant coffee.

Results and discussion

Some of the main challenges in teaching the course are team work in teacher-selected groups, very open-ended problems, lack of relevant data for detailed design work, and different cultures working together (about 50 % of the students are non-Danish). These issues will now be discussed in more detail.

Team work in teacher-selected groups

From the very beginning, it has been an aim of the course to teach the students how to work in teams of people with different professional and personal backgrounds. The purpose is to simulate a real working environment. About half of the students take this as an interesting challenge. The other half of the students is not comfortable and the main concerns are about relying on group performance rather than the individual performance as in most other courses

within our department. We use a simple personality test with four groupings in the process of putting the teams together. We put priority to having one of each personality type in each group but also prioritizes that all groups have a similar ratio of Danish to foreign students to enhance the interplay between students with different cultural and educational backgrounds.

During the semester we monitor the team work by having the students fill in a “narrative”, where they evaluate their own and the other team members efforts. This allows the teachers to take action if one or more students are not participating actively or the teams are simply not getting on. Usually the problems arising are due to either poor English skills (as the course is taught in English) which limits the capability of the student to participate actively in the group work or are due to free-riders who will not show up for the scheduled group meetings or will show up unprepared. We haven’t solved the language problems but we hope that the screening of the prospective foreign students will become more efficient in the future. With respect to free-riders we require that the team during the first week of the course formulate, agree on and sign a team contract on how they want to the project team to work together. The contract is handed in to the teachers as well and allows first of all the students to confront each other and ask for improvement according to the contract. However, the problem with free-riders usually ends up at the desk of the teachers after the hand-in of the first project or after the narrative procedure (usually after the first two projects). We then arrange meetings with both the free-rider but also with the remainder of the group to identify with is the core of the problem. In most circumstances, we end up with constructive conversations and we observe a clear improvement of the working habits of the free-rider but we also observe that the group usually works hard on including the free-rider in order to optimize the performance of the group.

In recent years, we have used teacher-selected groups in the first part of the course and student-selected groups in the final project. Both teachers and students are generally satisfied with this arrangement, though some students still feel that they should not be forced into groups with people they do not know and share grades with them.

Open-ended problems

In the final large project, the student teams must come up with a need by themselves and bring that need from a market analysis to a final product idea and describe a production of that particular product. During the project period we, as teachers, behave as mentors and try only to catalyze the process. Overall this works very well for most teams and so far all teams have managed to identify a relevant need. At the end of the course, the teams present their project to the other teams and there is an individual oral examination on the project report.

Lack of relevant data for detailed design work

Specifying product needs and detailed production planning are serious challenges. This is because it is difficult and time consuming to find relevant data

to use for detailed calculations (cost, equipment). In recent years, we have only gone to the level of setting up flow sheets in the case of production. This seems to be an acceptable way of handling this part.

Cultural differences

About 50 % of the students are non-Danish. This means that working habits and planning of projects are approached in different cultural styles. This can cause some frustration in the teams and we therefore spend some time the first day to explain the “rules of the game” and we let the student teams put together a contract as mentioned earlier stating how they have agreed to conduct the team work. All team members sign the contract. This has worked out quite well.

Conclusions

Based on more than 10 years of experience, we conclude that it is possible to teach product design to engineering students, but many students prefer well-defined and concrete assignments. However, it is essential also to educate engineering students to handle design problems and understand the customers using the products they produce. In future years, an increasing number of chemical engineers will be working on structured products.

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Relevance – The CDIO principle is practised in the course through customer interviews, idea brain storming, selection of ideas, simple experiments, and setting up a production of a relevant product.

Submission Category - paper presentation.

Keywords – design, products, production, innovation

WORKING- VS. EDUCATIONAL PROCESSES IN SOFTWARE ENGINEERING VS. CDIO

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ABSTRACT

The relatively short history of IT can unfortunately point out a number of failing projects concerning missing deadlines, functionalities, low quality, etc. Theories and techniques have been developed, to meet inherent problems and challenges. But also software process models, that is ways of working, where several typical activities within software processes have been emphasized. Still, the use of software also seems to bring even further requirements on new techniques. A conclusion is therefore that, besides from some core fundamentals, inherent parts of IT are, by necessity, evolving in themselves.

When it comes to educational systems, an appropriate set of theories, techniques, and principles should be taught to prepare for working in software industry. Still, this is not enough. A software engineer actually needs to be able to handle all the steps of a software process. That is, educational systems have to find ways to support teachings, not only in theories, techniques, and principles, but also in ways of working that hopefully should correspond well to the practices of software industry. Furthermore, students should be gained by getting educational support to meet and handle the ever changing future.

This contribution presents project based approaches where the process of developing the project result should have several benefits. First, it should provide a basis for training core practices of Computer Science, second it should prepare for software processes, i.e., ways of working in software industry, and third, it should aim for students being responsible for self learning. Especially, the third point is significantly important in a discipline of ever changing techniques. Inspiration is taken from well known Software Process Models. Such are models are shown to lie close to the CDIO initiative. Software Process Models are discussed, comparisons with CDIO are provided, as well as a case study on a project based course.

KEYWORDS

Project based learning, Education concepts, Software Engineering, Cooperative work, Evaluations for groups.

INTRODUCTION

Software Engineering is probably one of the most recent engineering disciplines. As such there have been major requirements put on that discipline to undergo appropriate transformations from immaturity to higher levels of maturity. This does not only relate to the need for that discipline in itself to be reliable, but also to the ongoing almost explosive change in amount of software that more and more is integrated into society. The latter, on

the other hand, is driven by pure commercial requirements, as well as requirements on security, health, entertainment, and so on.

According to David Parnas, a well-known expert in Computer Science and Software Engineering, software is the most challenging and complex engineering construction in human history. Large scaled software may include millions and millions of lines of code, where high requirements are put on functionality as well as quality, on levels of code as well as on software as a whole. Preparing students for real life software engineering tasks require exhaustive practice in programming skills, theory, and techniques. However, to meet the challenges of developing large scaled software products this is not enough.

The ability of fulfilling a software project corresponds to the ability of controlling and steering the working process that takes you there. That process may start from a position of low or even no knowledge of a specific subject, to a resulting software product, ready for deployment. That is, besides from technical skills, students are also gained by being prepared for the working process itself. Therefore, educational systems should provide ways of experiencing students, in Computer Science and Software Engineering, in such directions.

Several models of Software Engineering processes have been proposed. Typically, those suggest iterative and incremental ways of working, with frequent more or less formalized meetings for discussions and feedback. This, among other things, implies allowance for sets of requirements to mature throughout the process, avoiding mismatches between, on one side, expectations from stakeholders, and on the other side implementations of developers.

From the point of view of educators, the value of creating valuable and well motivated structures for educational purposes should be clear. The relatively new and innovative approach of CDIO proposes educational forms for engineering studies generally. However, in the perspective of the author, it is of course especially interesting to see CDIO in the context of Software Engineering studies. Interestingly enough, we can see that there are several similarities between suggested working process models of Software Engineering, and educational forms suggested through the CDIO initiative.

The contribution of this paper is mainly two folded, discussions of on working processes, and a case study in that context. An investigation on working processes of Software Engineering, and comparisons with the CDIO initiative will be provided. Moreover, project based learning of the educational system of the author's home department will be outlined. A case study on a project based course will also be outlined. Problems, outcome of the course, and possible improvements will be discussed.

SOFTWARE ENGINEERING PROCESS MODELS

By Computer Science we often mean the core theories, techniques and principles behind programming computers. By Software Engineering we normally mean something more, an engineering discipline covering all aspects of developing a software system, including handling requirements, design, implementation, test, deployment, and maintenance. Terminologies and concepts may however vary. Being a programmer may mean that you write a complete program. A software engineer rather implements only parts of a bigger system, in a team of developers. A software engineer also has to regard the mentioned aspects on software engineering ([7]). Furthermore, by a Software Engineering Process we mean all the activities included to fulfil a software project.

Software Engineering as a field was born in 1968 at a NATO conference covering the, so called, software crises ([8]). Software crises reflect on chronic failures of large software projects to meet requirements, quality, budget, schedule, etc. From that point several

Software Engineering process models have been proposed to meet the software crises. Some are listed below.

The Waterfall Model

The Waterfall model ([11]) is a general and natural model for software development. The model describes how to go through a number of steps to fulfil a software product. The steps cover activities such as, defining the requirements and analysing those, designing solutions, implement the software system, test the system, and finally put the system at an operating state and maintain it. Figure 1 illustrates this. The model also points out a temporal order where one step should be finished before starting the next. If, at operational state, failures are discovered at one of the previous steps, those are corrected and the following steps are then corrected according to that. This seems natural; however, a typical problem lies in the originally stated requirements, where those have an ability to evolve during the whole process. This is a result from increasing knowledge of those from the points of views of both the stakeholder, and the developer team. Furthermore, requirements may change because of different kinds of changing circumstances. Changing a requirement is normally considered very costly since that implies changing dependencies in the following steps.

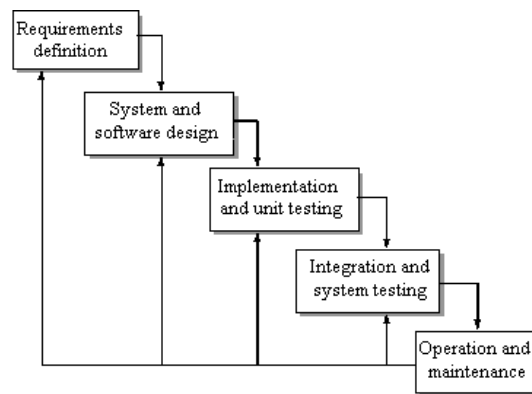


Figure 1. The Waterfall model ([11]).

Iterative and Incremental Models

To meet the problem of changing requirements, Iterative and Incremental process models are proposed. One such model is the Rational Unified Process (RUP, [10]), which instead suggests working in smaller increments of disciplines, such as, requirements definition, design, implementation, and tests. This is briefly further discussed in the sequel.

A selected number of requirements are analysed, designed, implemented, and verified. At the end of an increment there is a meeting with customers to discuss the system so far, how the requirements are met, and to discuss the proceeding work. In this way, and through an exhaustive documentation, the work should be monitored and validated, and serve as a basis for building the next increment. That way of working is iterated until the project is fulfilled.

Briefly, the process model includes four main phases:

- Inception: Set the business case, and define the main requirements
- Elaboration: Develop an understanding of the problem domain and design the system.
- Construction: program and test.
- Transition: Deploy the system in its operating environment

For each of those phases a varying amount of effort is put into the disciplines of requirements, design, etc. This is illustrated in Figure 2, where time scale goes from left to right, and effort on disciplines per phase is outlined. An interesting point of view here is that also project management is included as a discipline of RUP. Project management, here involves planning the process, controlling it, handling risks, etc. For more information, [10] is outlining this process model, for educational purposes.

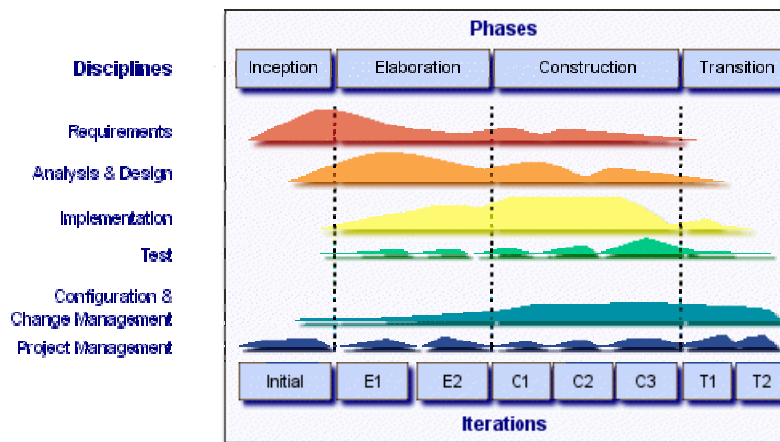


Figure 2. Phases and Disciplines of RUP ([10]).

eXtreme Programming, an Agile Process Model

While e.g., RUP meets changing and unclear requirements, criticisms have been pointed out towards RUP, and other similar process models. Those, among other sides, concern the exhaustive documentation, where that is a part of controlling the process from a management point of view. The main intension is to be even more agile to changing circumstances, and exhaustive documentation is here considered counterproductive. Here is the software rather considered the most important, not documentation. While, e.g., RUP, may be considered as a management choice of process model, agile process models are more considered as the programmers choice. Still, criticisms towards agile process models have also been pointed out, and concern the inappropriateness for large scaled projects. For projects with need for teams larger than about twenty developers, other forms are recommended.

The eXtreme Programming ([14]) approach put several aspects to the extreme. For instance, design should be simple, and tests are done totally integrated with implementation. Furthermore, the customer is one in the team, constantly available for questions on requirements, for feedback on prototypes, and for prioritizing amongst tasks to do next. Those aspects, and others, are captured and illustrated by Figure 3. For more information please see, for instance [14].

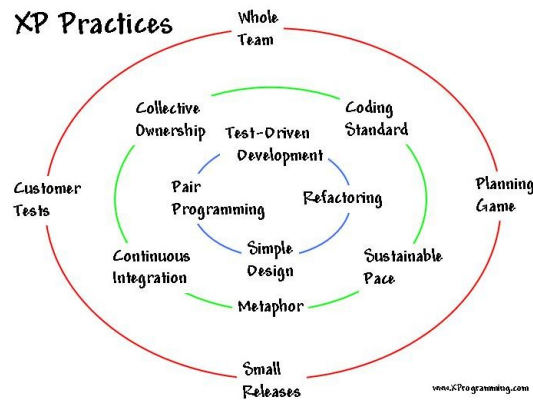


Figure 3. Practices of eXtremeProgramming, ([14]).

Summary

The immaturity of the field of Software Engineering, the lack of experiences, the software crises (see discussion above), in combination with an almost explosive growth of the amount of, and need for software, have forced that field to come up with solutions. Process models regard ways of working, guidelines to reach the goals of fulfilling software projects in time and within budget, and meanwhile meeting the requirements of the customer, in qualitative ways. Still, even if a process model seems to be appropriate that does not guarantee that the project will be successful. It can only increase the probability for that.

From an educational perspective the software engineering process models provide a two folded interest. On one hand, if software industry maintains process models, it is of interest to train students in those for them to get appropriate experience. On the other hand, the ways of working proposed through process models may bring inspiration to educational processes. That is, theories, techniques, and principles, may be learnt in a context of an educational process similar to a software engineering process. How this has been approached is further discussed at the section Project Based Education.

SOFTWARE ENGINEERING PROCESS MODELS VS. CDIO

While Software Engineering process models have its origins in software crises, the CDIO initiative ([13]) origins from a desire from industry for more mature students. Maturity does here relate to capabilities of putting core engineering knowledge into practice in real world projects. Besides from real world problems, real world projects also concern a process of working phases to move from originally stated problems to fulfilled solution under operation and maintenance. Typically, at an abstracted level there are four main phases. The first phase concerns setting the business case, catching the main requirements, and estimating required resources, in terms of time, money and personal. The second phase typically stands for high level design, the third for more fine granular design, and constructing the product. Finally the forth phase stands for deploying the product, putting it to an operating state, and eventually maintaining it.

The innovative CDIO initiative provides an educational support to meet the industry desires for more appropriately prepared students. Here the letters CDIO, stands for Conceive – Design – Implement – Operate, that in turn in much corresponds to the mentioned four phases. For more detailed information on this please see [13].

Now, returning to the previously described Software Engineering Process Models, the same four main phases have also been outlined in that context. No matter what model is used we can see the same core activities, however, more or less parallelized. Main goal of the phases of the RUP model are (for more detailed information, please see [10]):

- Inception, Establish the business case for the system.
- Elaboration, Develop an understanding of the problem domain and the system architecture.
- Construction, System design, programming and testing.
- Transition, Deploy the system in its operating environment.

Again we can see the close correspondence between the concepts. So far they may be interchangeable. That is, so far, following a Software Engineering Process Model for software development in education could as well be done by following a plan for using CDIO. Now, CDIO have been put into rather exhaustive evolvment, and tested out in itself, and may therefore meet the mentioned desires from industry. The conclusion should therefore be that following a Software Engineering Process Model for educational purposes should correspond to similar desires from software industry. That is, in the sequel, when such models for project based learning are discussed, they could as well be seen as CDIO based projects.

Actually, a more detailed analysis is required for comparisons. As an example, assessing the work is done in different contexts for different purposes and because of this, probably looks different; however, this is put outside the scope of this contribution. In the sequel it is assumed that assessing project based educational work is done according to how to measure progress of Software Engineering Process Models.

PROJECT BASED EDUCATION

According [6], project- and problem based learning forms are attending more and more interest in Swedish educational systems. Pupils of elementary school more and more work in contexts of specific themes, where teams of pupils drive their own process to get and present the appropriate information. This in turn will probably contribute to a sense of familiarity for those later on, when it comes to project based learning in teams of higher education.

Motivations

In [5], several examples on project- and problem based learning at Swedish universities have been pointed out. Furthermore, [5] presents a number of motivating points for developing software systems in project teams, and especially reflecting that on higher education.

- First, if systems are supposed to be interesting enough, those are seldom developed in a scope of one or two persons. Furthermore, real world problems normally inherently have a scale and complexity that is not possible to manage for only a few persons. You may need ten, twenty, or even hundreds of people to fulfil a complex task.
- Second, in software industry most often projects are performed in teams of developers. Providing practice in this should therefore also be essential in higher education for preparing students for software industry ways of working.
- Third, the Higher Education Ordinance of Swedish National Agency for Higher Education points out several desired competences engineering students should have that probably may be developed though project based educational forms ([5]).
- Forth, projects often involve needs for investigating techniques and knowledge that in advance may be unknown for the developer. Thus, project based learning in itself

supports overcoming the challenge of taking responsibility to actively find new solutions to problems. This is perhaps especially essential in software development where we can see an increasingly variety of proposed techniques for an increasingly amount of different purposes.

The forth point above illuminates on the impossibility in the ambition of providing a complete picture of all parts of computer science to students, perhaps especially because of constant changes in techniques. All we can offer are restricted overviews, and in depth studies of some selected concepts. The ambition we can have is to provide an appropriate fundament for further investigations. In [3] this is pointed out through:

"Universities are supposed to enable their students to engage in effective action in situations they are going to encounter but as the future is increasingly unknown, these situations are impossible to define in advance. What universities have to offer is knowledge and therefore you have to prepare for the unknown by means of the known".

Finally, the background and the reasons behind CDIO ([13]), with impact and desires from industry on engineering studies, strengthen the motivations for project based learning even more. That and the growing interest in CDIO in itself may serve as great inspiration in developing project based learning forms further.

Project based learning at home department

The main focus on [5] lies on studies of project based learning forms outside of Sweden, especially China, and Arabic countries. The result shows a significant discrepancy between Sweden and those countries, in the use of such learning forms. The reason behind the studies of [5] is the quite great amount of students from those countries that have been, and are studying at our home department. This in turn, and also with respect to the above pointed out reasons for project based learning, has inspired us to introduce project based learning at several courses, starting already at the first semester.

At the section below, a case study with a project based course is provided. Typically students of that course have been involved in projects as listed below, where the author of this contribution has been more or less participating as a supervisor or teacher.

- Project at the end of course in fundamental programming, about 5 hp, first semester. The project is done with an iterative and incremental process style (see section on Software Engineering Process Models, for more on this). There is one project group meeting with a supervising teacher each week, during a five week's period. For each meeting the students shall upload and discuss documents on requirements, risks, design, and project plan. Progress in documents and software product shall be shown, and that also forms the basis on which student's course grade is assessed. A project group involves about four participants.
- Project at the end of course Object Oriented Programming, about 5 hp, second semester. This corresponds very much to the first semester project, but with impact from more detailed teachings in design principles, and programming techniques.
- Software Engineering, about 7.5 hp, second semester, year 2. The project is based on an eXtreme Programming (XP) process style (see section on Software Engineering process models, for more on this). It does not have one meeting per week between teacher and project group. Instead, there have been full days of working XP-like. Principles and techniques are covered through the project.
- Software Projects, on 15 hp, first semester, third year. In contrary to previous courses projects are here performed in large project groups. Project group meetings take place every twice week, where a number of documents should be uploaded and

discussed. Principles and techniques are covered through the project. More information on this course is provided in the Case Study section below.

Normally a project ends with full days of project presentations where the result of the work of the project groups are shown and discussed. In some cases this is done in front of a common audience and with invitations of newspapers ([9]). Grade is generally based on process, presentation, final software product, and project report.

A CASE STUDY

The case study is based on a course that covers 15 hp, and has been running at the first semester (autumn semester) of the corresponding students' third year, which also is the last year of those. The number of students was about 60. Each group were quite large, about 20 students, which in turn were divided up into sub groups of about 4 students. There were originally 3 groups, one of those was split into two halves, because of too hard cooperation problems. This paper will focus on the two remaining groups of about 20 students. Group 1 is a group with solely Chinese students. Group 2 is mixed of a number of nationalities, such as, from Sweden, Arabic countries, Cameroon, and more. That first division into project teams were done by teachers, where the decision was based on experiences from previous desires from students. The course was chiefly provided by one main teacher, which is the author of this paper (the course teacher). Besides from that, there were three co-teachers mainly assisting at developing and participating at some of the course labs.

System structure

The project itself concerns aspects of a so called *interactive house*. The technicalities of the project were presented at *STCC, Hangzhou China, 2010* ([4]).

In short the interactive house project should consider several distinct parts, including an embedded server and database, web based interfaces, remote controllers in terms of mobile phones, a physical simulation of a house (including light, fan, radiators ...). Parts of an interactive house should, furthermore, communicate through well defined communication protocols. Figure 4 illuminates on the core system structure.

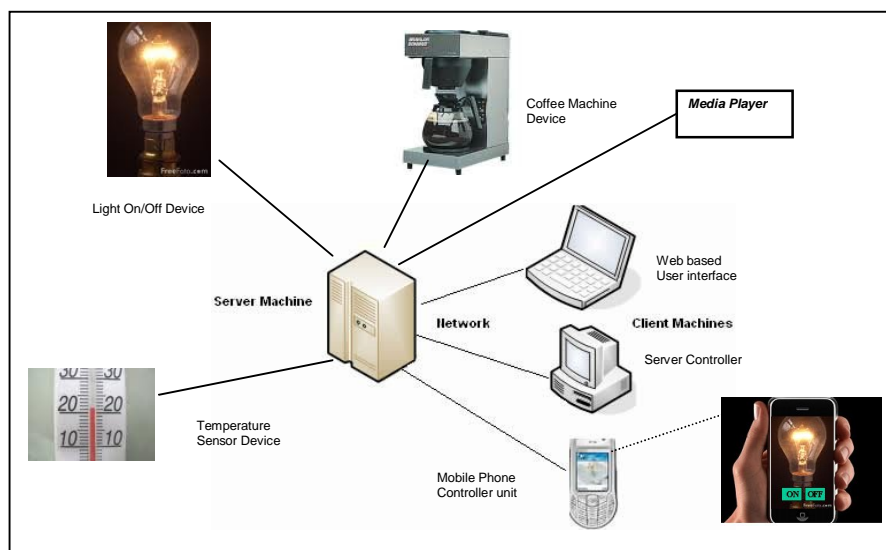


Figure 4. Illumination of system of the Case Study ([12]).

Communication towards the interactive house may be performed from both computers, and mobile phones, at the same time, and there may be any number of those. Mobile phones may be the most modern smart phones, or more traditional mobile phones. A media player could be built as a piece of software with a graphical user interface (GUI) from which pieces of music are selected and played. The simulation of the house is done through a small scaled physical house model where communication with light, door locks, fan, sensors for temperature, etc, is provided through an Arduino micro controller ([1]). Figure 5 illuminates on the latter. Other devices such as coffee machines, etc. are completely simulated in software.

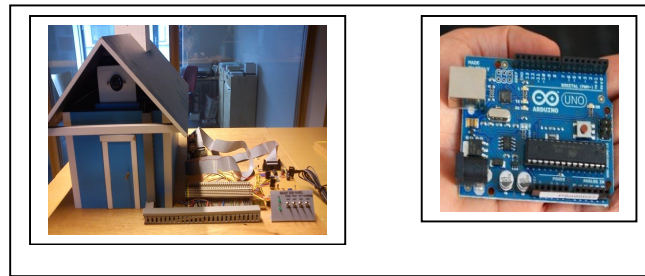


Figure 5. House simulation with Arduino micro controller board ([1]).

Project team structure

The project team was mainly divided into sub groups with respect to sub tasks of the project as a whole, see Figure 6. That was more or less decided from the start by the course teacher. That is, one group handled the server with a database, two groups handled the house devices, one for software simulation, and another for the physical house. Furthermore, the control units were developed by two groups, one for a web based user interface at a computer, and the other one for the mobile phone. Sub tasks developed in sub groups aims for parallel developments, however, that also requires well defined communication interfaces between functionalities. Therefore one group was especially dedicated to that task. Finally, one student was selected by the teacher as the Project Manager, with a leading role, and one student was elected Requirements Manager, with specific responsibility in communicating the system requirements between teacher and project team members. Moreover, each sub group had their own sub group leader.

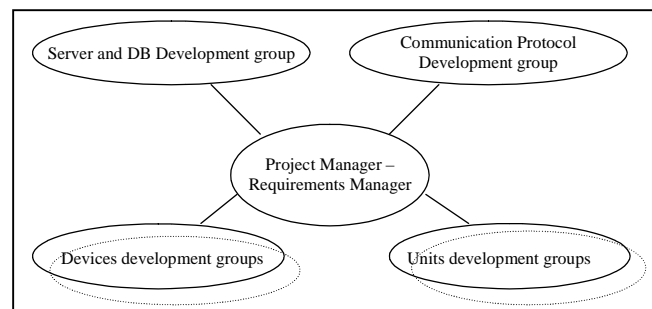


Figure 6. Project group structure.

All in all there were put high demands on the student groups to manage communication and negotiation to fulfil their main project task. Communication with course teachers was mainly

done through the dedicated Project Managers. Running the working process should here correspond close enough to well known Software Engineering process models where the teacher also plays a role of a customer or “super boss”.

Techniques, Theories, and Practices

To be able to develop a system of the case study, some theoretical and technical knowledge is needed. Moreover, knowledge of practices is desired to work in teams. First, at the point of the course start, experiences that students should have had from previous courses, and are crucial for the course, include:

- General programming skills
- Use of IDE (Integrated Development Environment) for developing software
- Software design and use of tools to develop software design
- Communication protocol for general distributed communication (such as, TCP/IP based communication)
- Digital techniques
- Running an iterative and incremental project (see e.g., Subsection *Project based learning at home department*)
- Configuration management, to handle repositories of developed pieces of software, and different versions of those.

The course will give opportunities for practising those subjects even more. Besides from those, the project of the case study also put demands on knowledge in further subjects, as listed below. Even more, the course in itself stands for a step in the educational progress where students are exposed to more professional tools, and ways of working. Further subjects taught at the course include:

- A more advanced and professionally used IDE, with plugins for integrating software design and programming.
- Developing software for mobile phones
- Developing software for web based interfaces
- Handling the physical house model
- Software Engineering subjects. More on requirements, qualities, design, etc. Also more on working processes.

The last point above was typically covered at lectures and practised during the course. Experiences on the first four points were typically provided through labs. The three middle points should be practised by all students. Still, while the labs provide a preliminary knowledge, sub groups especially covering those subjects need to dig more into needed implementation details, by themselves.

Outcome – students

An interesting point here is the big variation of nationalities amongst the students, in several cases with backgrounds in education systems where project based work seem to be quite uncommon. However, at the course of the case study, the students should have some skill in working with projects in teams (see, Subsection *Project based learning at home department*). This, together with use in English as the main educational language should aim for more or less fluent communication.

Another interesting point is that in several cases, students of one and the same sub group were living several tenth of miles from each other and only seldom with natural in person meetings. Yet another interesting point was that the groups should in much control their work

by themselves, where main control was performed by a Project Manager and delegated sub group leaders. Communication is therefore significantly critical.

Initial phase

At an early full class meeting the students were divided into project teams, with dedicated Project Managers. After that a Requirements Manager should be selected, the project manager should have a main role in this selection. Then the project teams should divide themselves into sub groups, everything should be controlled and steered by the project manager. Still, sub groups of Group 2, were typically very much geographically correlated. Swedish students formed one sub group, Cameroon students formed one sub group, and so on.

Very early the students agreed upon a technical basis from communication. Group 1 established common email lists to distribute information. Group 2 chose a Google based configuration management tool. For each comment uploaded at a common repository, each member of the project group should automatically get an email about the discussed subject. For the sub groups, communication was typically performed on more personal email basis.

All in all there was an active and interesting start. The first meetings with teachers were active with many discussions on design on parts of system, as well as on system as a whole. Much of the discussions concerned communication protocols between system parts. Those discussions were needed to be able to develop the system parts as independently as possible.

As time goes

After the first about seven weeks of the course, progress for both Group 1, and Group 2, seemed to decrease. Technical difficulties were handled, but especially communication between sub groups seemed to cease. Project Managers seemed to loose control over sub groups, and their activities, and little or even no result was shown.

Typical causes of the problems seemed to be: higher priorities put on parallel ongoing courses, low authority from Project Managers point of view, lower interest in the course than initially, a few students even decided not to follow the course.

Meetings with teacher seemed not to be as valuable as previously. Mostly the still active students thought they didn't get feedback enough from teacher, and that they were forced too much to tackle the problems themselves.

Finally, to handle the situation, the course teacher had to give an order to the whole project groups to attend at mandatory meetings led by the course teacher. Not only had the sub groups have to fulfil their own sub task, but also, everything should be integrated to fulfil the project as a whole, a challenge that is not trivial in itself. By the end of the course Group 1 seemed to be safe, while Group 2 was at the edge of failure.

Project presentation

The presentation of the project is a part of the examination, and is done by each student, from each sub group, from each project team. That is, one project team presents its result from the view of the results of the sub groups. A presentation is provided to all other co-students of the course, and covers the work that is done, design, qualities of the system, etc. Each sub group should also prove that their part work in isolation, that is, without involvement from the rest of the project parts. That is typically done by simulating the context,

and run the part in the simulated context. Thereafter a project team should show a fully integrated working system.

Group 1 have a good presentation, in detail as well as at a whole project level. The following discussions with audience and course teacher are also good. The general judgement is however that the limits could be pushed even further.

Group 2 were risky to the end. However, through hard and intense work they managed to fulfil their tasks. The result was surprisingly good at every level, and from several aspects. The final run of the complete integrated system was actually even surprisingly impressive.

Outcome – course teacher

In several aspects the course was new both to the students and the course teacher. Techniques that previously had not been used in education at the course teacher's home department were introduced in this course. The project group sizes, and project managers and sub group leaders, were new to both the course teaches and students. Leaving more responsibility to the students in this way introduced more work to the course teacher. Conflicts had to be handled, and one of the originally three groups had to split because of impossibilities in cooperation. This on the other hand led to special treatments for those groups later.

At course start a quite great amount of course material was exposed to the students. Lectures on techniques, Software Engineering, and the purpose of the project itself had to be provided to start the students' work as soon as possible. After the first weeks the students had a higher grade of self responsibility for their work, and feedback from course teacher was delivered through the project group meetings.

As described above, initial meetings and also lectures, were intense, active and exiting, not only to students, but also to the course teacher. After the first weeks, progress and interest from students' point of view, seemed to cease. After those first weeks, the course teacher also had fewer amounts of lectures, and a conclusion may be that this contributed to lower grade on activity and higher sense of insecurity from the students' point of view. Challenges of teachers typically relate to encouraging groups, and especially project managers, and group leaders to carry on. When the situation seemed to become more critical the course teacher found that the upcoming crises had to be handled with the whole project teams. Even though those meetings seemed to encourage the students further, the crises were still there. The partially successful outcome at the final project presentation was both a sense of success and relief also for the course teacher.

Further challenges lay in the evaluation of the student work. Also here the working process plays an important role since this should be integrated in that process. Each twice week students should upload documents on design, test plans, etc., to show progress of work. The documentation upload is done per sub group, and correspond to an iterative and incremental way of working (see Subsection *Iterative and Incremental Models*), where such documents are used to validate the state of the process. In the context of the course such documents provides a basis for evaluating student work and set the grades. Moreover, at the project group meetings those documents are discussed.

The result of uploaded documents mirrored the state of the course. Initially documents showed progress, however later there was a lack on progress or in some cases there were no uploads at all. From the course teachers point of view a situation turned out where there a balance had to be found between passing students, and failing them completely on the basis of a failed working process. Fortunately, through uploaded complementary documents later, the course teacher avoided the situation of failing students on that basis.

A conclusion may be that the course teacher should have taken a more authoritative role, more leading, and provided more careful comments on work done by students. Furthermore, the course schedule should be changed in favour of lecture contents more spread over the whole semester. Even more, project meetings should not only concern project managers and sub group leaders, but at least occasionally involve all project team members.

Course evaluation

There are mainly two ways of performing a course evaluation, a formal investigation, and an informal investigation. At the home department of the author the formal investigation is done through an electronic interact able document that is sent to all course participants. Thereafter, after the form is filled in, it is automatically returned and compiled together with other filled in forms. This has also been carried out at the current course.

Moreover, after the project presentation, there was a final mandatory meeting between course teacher and the different project groups. At that meeting several discussions on the outcome of results as well as on the course itself were taking place. All in all, the project and the course were considered very exiting. Below some outcomes of the discussions are pointed out.

On the positive side:

- Fun and challenging project
- The course aimed for studies of new techniques
- The course provided new insights on working in large groups

On the negative side:

- To big groups. Even though this was a good experience, the group sizes still were considered too big.
- Not enough feedback on work from course teacher.
- The authority of the student project manager was not strong enough. Support from course teacher was needed.

The formal course evaluation was in much reflecting the same comments on the course as the informal discussion did. However, the number of answers was actually too low for a significant course evaluation and validation.

Besides from the course itself, the course teacher could see that many bachelor thesis works could extend the core of the project in several directions. Such extensions concern security, usability, and more. A list of proposals for bachelor thesis projects was developed by the course teacher. The reactions from students that had taken the course were positive, and about all of the proposals were selected by students for bachelor thesis work.

Possible improvements

Both positive and negative criticism should be reflected upon. The course will take place again autumn 2011, and modifications should be considered. The outcome of bachelor thesis works will probably bring even more substance to the project.

The project in itself may be further specified, that is, the system requirements should be more precisely described. The course teacher should supervise the project more, at a level of system requirements, and qualities, i.e., should stress the requirements and system qualities even more.

Groups should be smaller; still there is probably a limit at about twelve to fifteen members of a project team. Below that number it may be hard to fulfil the goals of the project. The course teacher should probably have more meetings with the whole project groups to avoid dips and support ongoing progress. At such meetings the course teacher may clarify aspects of the project as well as on the work.

SUMMARY

To meet the requirements of engineering industry there is a need for substantial experiences in core knowledge, i.e., theories and techniques. Still, industrial engineering processes require more than that. Demands are put on flexible ways of using such knowledge appropriately. Moreover, fulfilling complex tasks necessitates analysing, and designing such tasks before they may be implemented. That is we also have to consider ways of working with problems that furthermore most often will be done in teams of developers.

Project based educational forms may be motivated by at least three reasons. First, they provide basis for practicing core knowledge in appropriate contexts. Second, when projects scale up in size and complexity, those are by necessity solved in teams of developers. Therefore, the process of developing the project requires ways of working in teams. Practicing this means maturing students to approach similar ways of working in industry. Third, projects normally involve activities or techniques originally unfamiliar to the developer. That will put further demands on the developer to meet those challenges. Meeting such challenges means taking responsibility for updating your own experiences that in turn means that you are prepared to meet the changing future and correspond to evolving techniques, and disciplines.

This contribution has put a focus on project based work. In Software Engineering education such ways of working may be inspired by well known Software Engineering process models, as well as by the innovative CDIO initiative. Software Engineering process models aims to guide software developer teams through a qualitative process, to qualitative results. CDIO aims to give valuable practice to engineering students for those to more appropriately fit into product development of engineering industry.

The contribution shows several similarities between Software Engineering process models, and the CDIO initiative. The conclusion is therefore that those approaches are more or less interchangeable, that is, using a Software Engineering process model for educational purposes could be seen as following the CDIO initiative.

A project based case study has also been provided and discussed. That case study is based on a course implemented with a Software Engineering process model, but could as well be seen as implemented through the CDIO initiative approach. Furthermore, the case study is shown to give support for putting core knowledge in a context, as well as provide practice in working processes, and provide for students to explore new techniques to solve the goal of the project.

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Biographical Information

Daniel Einarson has a PhD in Computer Science and has several years of experience in teaching Computer Science and Software Engineering. Furthermore, the author has been experimenting with several different forms of software process models as models for educational forms. Moreover, with inspiration from the CDIO initiative the author will strive after developing the educational forms for Software Engineering even further.

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AN OBSERVATIONAL STUDY OF INFUSING DESIGN THINKING INTO THE CDIO FRAMEWORK.

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ABSTRACT

Design Thinking (DT) is a human centric way of designing product, process, system and services, which has the potential to provide learning opportunities for engineering students to explore human desirability, technical feasibility and business viability. This paper attempts to outline how DT can be infused into a CDIO framework in the context of capstone projects since they allow students to appreciate the whole product lifecycle at logical stages (i.e. C-D-I-O). Engineering students were asked to innovate on ordinary consumer products in order to make explicit the effects of the Design Thinking process for *transformative* solutions based on the insights gained from ethnographic studies. Salient points for reflection, based on project supervisor's observation as well as students' feedback are also presented. While DT may leads to non technical solutions, the author feels a need to skilfully steer engineering students to utilise some of their disciplinary knowledge and skills.

KEYWORDS

CDIO, Teamwork, Capstone project, Design Thinking.

INTRODUCTION

The Singapore Polytechnic has always aimed to provide an education where students gain knowledge and skills for direct assimilation into the industry. Since 2007, the school of Mechanical and Aeronautical Engineering in the Singapore Polytechnic has, in stages, adopted and implemented CDIO approach into its curriculum. The CDIO framework has afforded the school, a means to balance engineering science (knowledge) and engineering practices (skills) during lectures, tutorial and laboratory sessions as reported by Chong et al. (2009), Linda et al. (2009), Christopher et al. (2009). The CDIO syllabus (part 4) focuses on the creation of product, process and system building skills, reflects the importance of a good grasp of a product lifecycle. Soh (2010) had demonstrated that CDIO could provide a meaningful framework for capstone projects in the context of product development and at the same time, able to cover most of the CDIO skill sets. The CDIO skill sets which codify the attributes of an engineer, underscore the importance of matching engineering education and industrial practices. While most engineering product developments focus on productivity, quality and cost efficiency; there is a trend among innovative companies to focus on customers' unmet needs as their business strategy. This will require an emphasis on consumer empathy more than mere marketing input to product, process, system and service design and development. Brown (2008) noted that:

“Historically, design has been treated as a downstream step in the development process....as economies in the developed world shift from industrial manufacturing to knowledge work and service delivery, innovation's terrain is expanding. Its objectives are no longer just physical products; they are new sort of processes, services, IT-powered interaction, entertainments, and ways of communicating and collaborating....”

Kumar (2007) also highlighted that there is:

“a tectonic power shift in the relationship between companies and consumers. New methods of being customer-oriented are needed....There has been a power shift from producers to consumers caused by decreases in production costs and increase in customer choice....now we possess a deep knowledge of how to make things and an inadequate understanding of how people are living their lives”.

Kumar (2007) further pointed out that research that:

“leads to specific insights about *current* offering that will enable the company to make specific improvements....The trouble with this research is that it almost never leads to insights that could translate into *surprising* improvements or entirely new products”.

With the changing industrial landscape, educational approaches would need constant reviewing in order to provide students with meaningful learning experiences. Sternberg (2010), the author of “College Admissions For The 21st Century” pointed out that:

“People need creative skills to generate new ideas, analytical skills to determine if they are good ideas, practical skills to implement their ideas, and wisdom to ensure that their ideas help achieve a common good”.

Lindberg et al. (2011) also noted that:

“An isolated technical perspective entailing isolated analytical thinking can thus lead into an innovation trap: while spending much effort in the development of technically novel or reasonable solutions, the clients do not really see the solution’s distinctive value”.

Design Thinking (DT) with its emphasis in realizing human-centric (not technology-centric) products or services should be taught in schools. Of course, technology can be used to enable innovation. In most engineering product development, established needs are typically provided from marketing research. DT encourages engineering students to explore the *unmet* needs that consumers themselves may not be able to articulate. This would require students adopt an attitude of empathy and sometimes relying on a “team based intuition” in order to derive insightful problem statements. This is where engineering students in the Singapore Polytechnic often feel very uneasy.

Cheah (2010) noticed that:

“Concepts such as ethnography (observation analysis of consumer behaviours to identify desired experiences) and designing consumer touch points (to deliver desired consumption experiences) prove too abstract to our students who are more acquainted to the systematic problem-solving of engineering education”.

Infusing DT into CDIO framework in the context of capstone project could be one way to provide a systematic approach that engineering students can readily accept. DT also promotes teamwork, critical thinking and communication skills as Dym (2005) pointed out:

“Design Thinking reflects the complex processes of inquiry and learning that designers perform in a systems context, making decision as they proceed, often working collaboratively on teams in a social process, and “speaking” several languages with each other (and to themselves)”.

This paper attempts to outline how DT can be infused into a CDIO framework to impact on user experiences. Capstone projects were used for the study as they allow students to see the whole product lifecycle at logical stages (i.e C-D-I-O). Engineering students were asked to innovate on ordinary consumer products in order to bring out the effect of the Design Thinking process for *transformative* solutions based on the insights gained from ethnographic studies

DESIGN THINKING AND ENGINEERING DESIGN PROJECT

Design Thinking is a human centric way of designing product, process, system and services. It is usually deployed to generate users' unmet needs. Methods may vary and evolving, but they have specific framework: Empathy – Ideation - quick prototyping – test/feedback. It is worth pointing out that *quick prototyping* refers to creating many inexpensive and rough conceptual artefacts, to promote deep thinking of issues and generation of ideas. Brown (2008) called DT “a methodology that imbues the full spectrum of innovation activities with a human-centred design ethos...it is a discipline that uses the designer’s sensibility and methods to match people’s needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunities”. Dym (2005) defines Engineering Design define as “a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients’ objectives or users’ needs while satisfying a specified set of constraints”.

A quick cross reference of the characteristics between Design thinking and Engineering Design in the context of school projects is illustrated by table 1.

#

	Engineering Design Project	Design Thinking Project
Objectives	Specific (starts with design briefs)	Fuzzy (establish design briefs)
Intention	Improve current needs	Derive unmet needs
Inputs	marketing research/ Supervisors	Ethnography
Members	From related fields (technical)	Prefers multidisciplinary teams
Process	Systematic	Chaotic
Solution	Technical	Depends on ethnographic insights

Table 1: Characteristics of Engineering Design versus Design Thinking Projects

From table 1, DT activities can be a good complement to engineering design project and it is clear that DT activities must precede engineering activities. As both design thinking and engineering design have “design” as a crucial component, design activities can be the coupling point in the CDIO framework (see figure 1). Hence, conceiving of engineering concepts can be part of the DT activities. For engineering students, it provides opportunity to explore and think beyond technological solutions. Design Thinking promotes holistic and creative ways in analysing problems. It typically gathers inputs from the people, cultures, objects, media, space and services. Students will learn about teamwork and be humbled to value opinions from all walks of life. The story telling session (i.e group sharing of insights gained during ethnography) also serves to sharpen students’ presentation, communication and critical reasoning skills. Highly hands-on, DT process promotes active and experiential learning. Being holistic in its approach also promotes integrated learning experience.

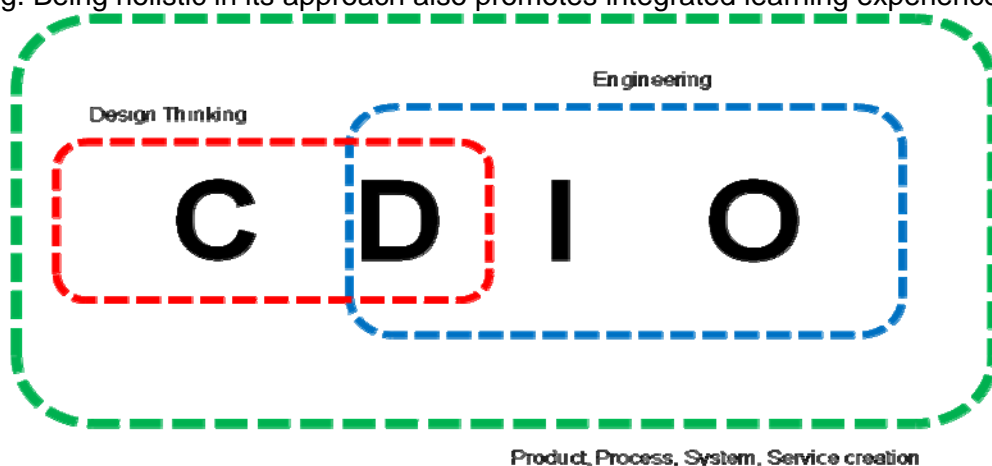


Figure 1: Design activities as coupling point.

DESIGN THINKING PROCESS

Usually, a commercial product, process, system or service development starts with some marketing inputs and engineers would dive straight into generating technical concepts and solutions. Creative ideas would still typically revolve around technical issues rather than some innate needs of consumers. In design thinking, team members are encouraged (preferably from different background) to use designer's sensibility to derive problem statements through a rigorous ethnographic process. Ethnography involves studying subjects in their natural settings, which usually include a field trip to *observe* human behaviours, *interacting* with them and *shadow* their lifestyles. Ethnography promotes looking at an issue much deeper than the symptoms faced at hand. Designers record all observations into their journals and prepare storyboards comprising of elements such as journey maps, mind maps and photographs. These storyboards help to prepare students for their story telling sessions. In the story telling session, team members share all insights they have gained to generate "bug list" or issues. The issues are then categorised. With issues identified, the team will work on a user centric problem statement which follows by brainstorming for ideas. Ideas were later categorised/ filter off (not meeting vision) and converge into key functions of the product. Next, the tinkering process encourages thinking by doing. Team members will make rough sketches, low resolution models (using cardboard, clay, wire, stick...), and sometimes even act out a scenario to illustrate their concepts. New insights may pop up. Another story telling session follows. By then, the team will have some consensus on what they WANT to do. NOT what they CAN do. By leaving no stone unturned, engineering development process can now begin. From figure 2, DT is represented by the C-D stages whereas Engineering Design is represented by the D-I-O stages. While "Design" in DT focuses on user desirability, "Design" in engineering design would touch on technical feasibility.

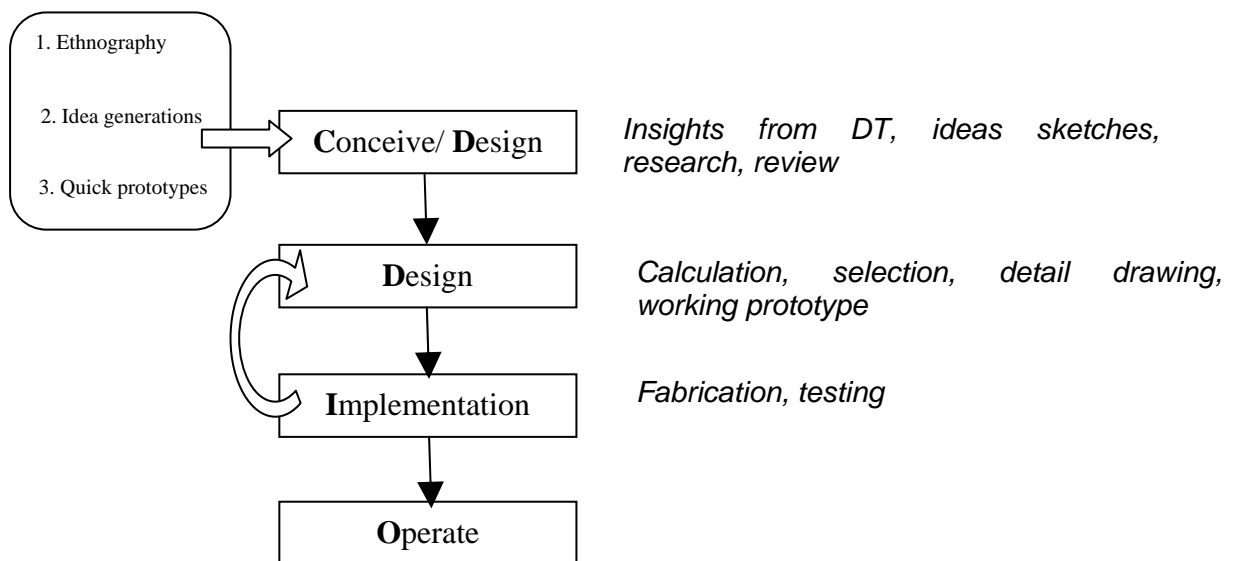


Figure 2: Coupling DT into CDIO workflow.

A CASE STUDY OF DT CAPSTONE PROJECT FOR ENGINEERING STUDENTS

The school of Mechanical and Aeronautical Engineering in 2010 had piloted DT activities by identifying 10 capstone projects to innovate on various mechanical products falling under the category of "green", rehabilitation and recreation products. The following figures illustrate some major milestones of a DT project by a group of aeronautical students who were asked to innovate on new concepts of playing toy guns.

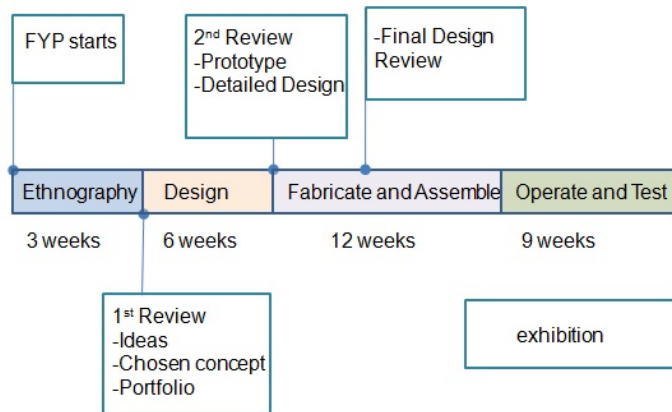


Figure 3: Capstone project time schedule.

Ethnography

There are many tools available for effective ethnography. The author had introduced his students to the Contextual Design Technique developed by Beyer et al. (1998). Contextual Design captures the field observation data into 5 Work Models (i.e. Flow, Sequence, Physical, Artefact, and Cultural). The work models allowed the teams to focus on interaction between humans, equipments, process and environments. They also enabled research on artefacts, cultures, philosophy, arts, history. Figure 3 illustrates how ethnographic studies are transformed into storyboards using the work models. During the field trip, photographs were taken, sorted and pasted on five A1 size board corresponding to the 5 Work Models. This was an uneasy stage as members do not have an idea where they are heading. Much motivation was needed.

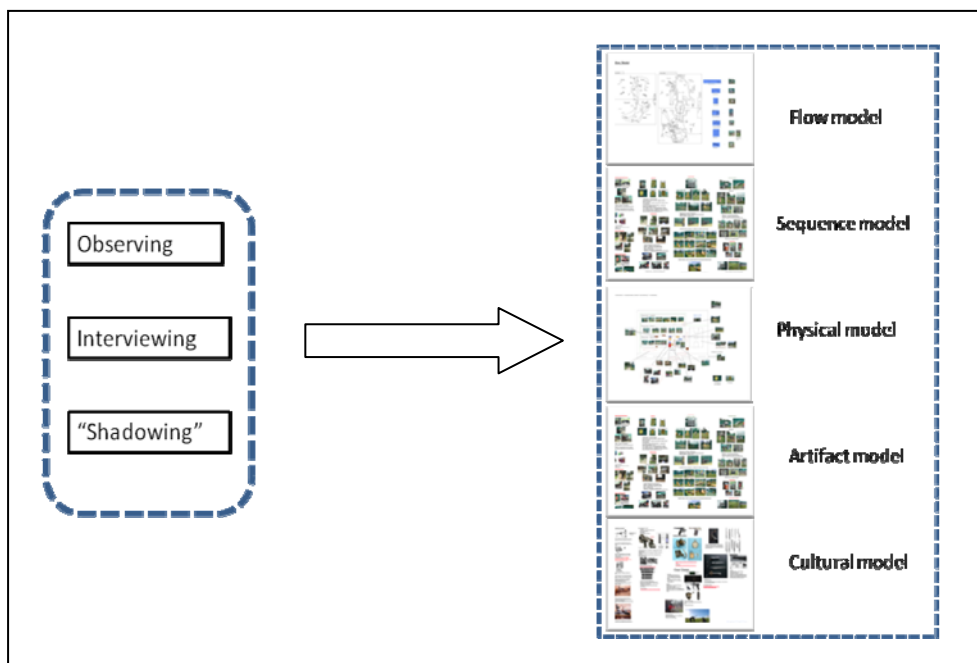


Figure 4: Transforming field data into storyboards.

Storytelling 1 (review)



Figure 5: Story telling

Team members took turn to share their respective models derived from field trips. Any issues and insights generated are immediately recorded on Post-It pad and pasted on the storyboards. Insights are keys to breakthrough concepts. For example during an informal discussion, it was realised that besides shooting “enemies”, an interesting theme plus social interaction can value add to the gaming experience. This had led to the incorporation of Cosplay and Gladiator elements into current paint ball game.

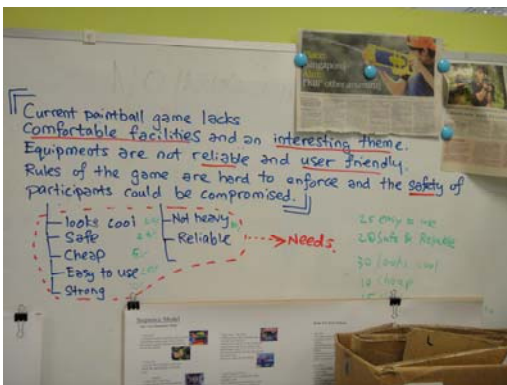
Classification of issues

Issues generated during the story telling session were classified into SPEC (Social, Physical, Emotional and Communication).



Figure 6: Classification of issues

Establish problem statement and needs



Students at this stage had acquired a certain level of understanding of the current situation and trends. Equipped with storyboards, derived issues and some intuition, the team spent many hours working on a good problem statement which addresses the most significant issues. User needs were also generated which will be transformed into engineering design metrics (i.e. measurable) during the engineering design stage for the purpose of selecting competing concepts.

Figure 7: Problem statement

Ideation



Figure 8: Brainstorming

Guided by the problem statement and user needs, students spent about 1 hour to brainstorm on various ideas. Students were given a target of 100 ideas.

More concrete ideas were derived by crafting out low resolution models during the tinkering session as shown in figure 10. Usual building materials for tinkering are foam, paper, cardboard, and acrylic. Various competing ideas can be selected by reasoning or through a voting system.



Figure 9: Voting ideas

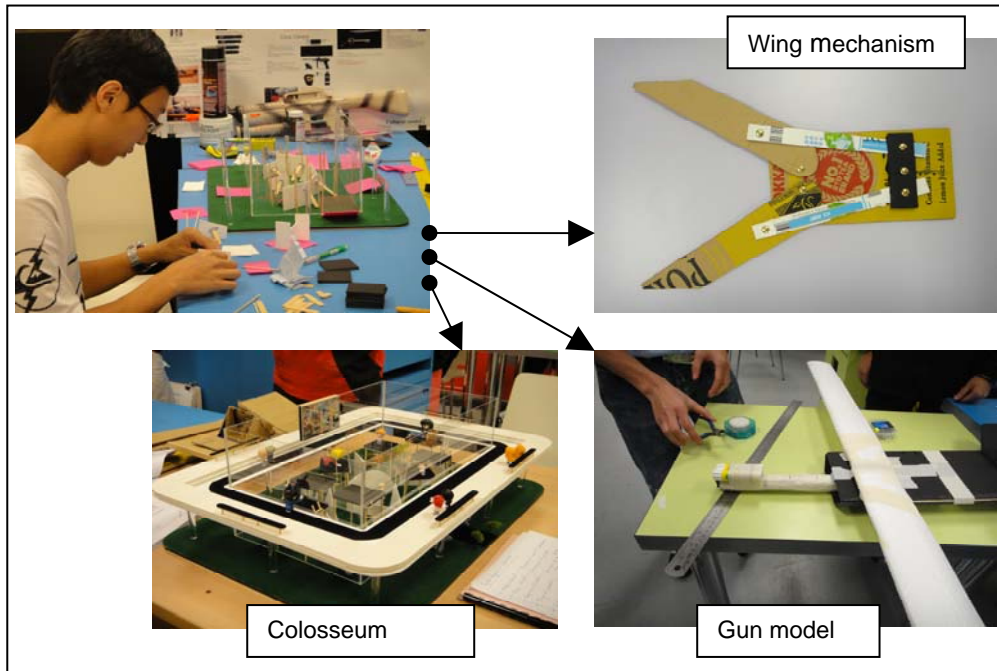


Figure 10: Tinkering on low resolution models

Storytelling 2 (review)



Figure 11: Second review

Students' ideas had converged at this point to a more feasible *product functions*. A second review was put in place where supervisor and co-examiner go through their “product and services” and share their thoughts on the technical aspect of the project. Iteration seemed capable of going forever and supervisor would have to steer them to complete their Conceive phase and move into the Design phase.

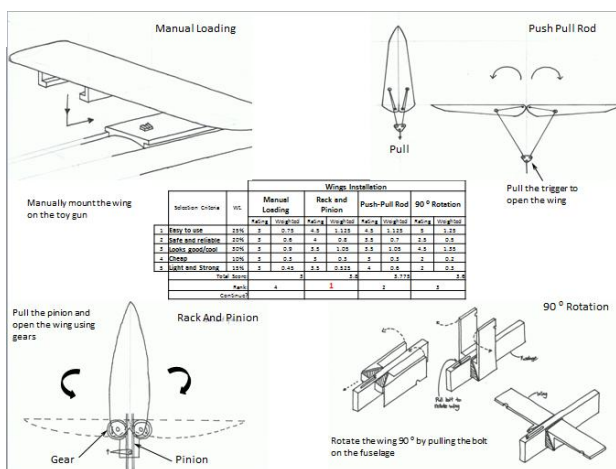


Figure 12: Selection of concepts

Within each product function (e.g Wing setting), there may be many *technical* concepts to choose from. The students used a weighted ranking technique against user needs (figure 12) to select the best solution. This is a popular concept selection method used in most engineering development process.

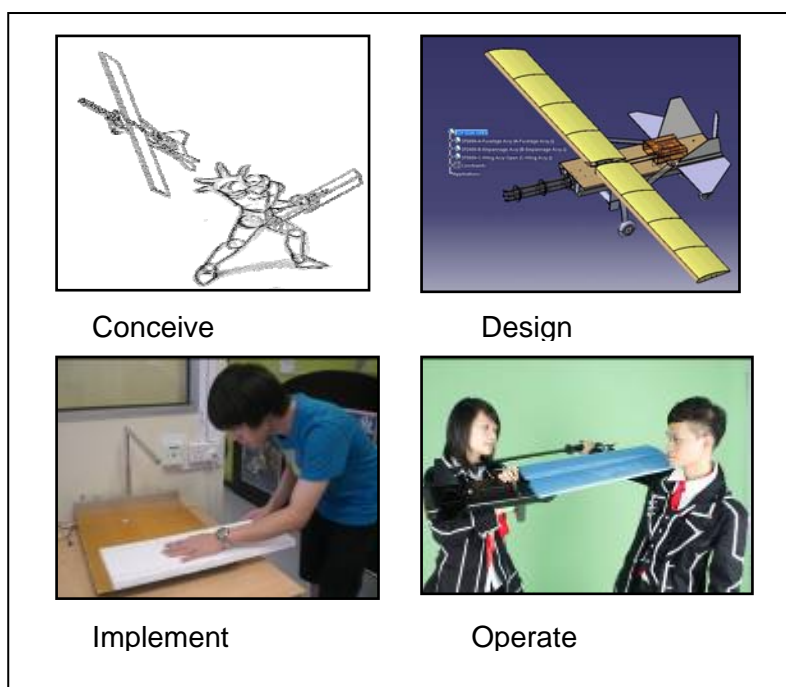


Figure 13: CDIO as milestones for capstone project

OBSERVATION AND DISCUSSION

Students' feedback

Upon completion of the DT capstone projects, selected students were asked to provide feedback on their learning journey.

[Tan Yu Da]: “The main problem faced including the design thinking is the extra time needed to discover the needs of the consumers. The research done on consumers was time consuming and sometimes we did not know what we were doing while other groups (i.e the non DT group) were progressing well. It also did not help that the judges for the progress review did not understand the design thinking process and gave us the same requirements as the others. The idea of design thinking did not go well with my group members initially, but after we got our final design, we felt that the design thinking helped us to make something that consumers would appreciate compared to what other groups were doing which have little market value. I feel that the design thinking process really force engineering students to be creative and be more mindful of the looks of the product rather than just focusing on the functionality of the product”.

[Xavier Soh]: “It can be frustrating that the ideas that came to our mind cannot be implemented immediately as design thinking required discipline to press on for more solutions from various angles. Nevertheless, Design Thinking enables us to generate far more ideas even when some might not be practical or realistic. I have this feeling that somehow; they can come in handy at some point”.

[Liew Chen Hao]: “Design thinking teaches me how to solve problems from consumers'/ users' point of view. Taking up a design thinking project was a challenge to me. Not only I have to constantly open to new ideas and solution, we also need to be mindful on technical feasibility of the ideas itself at some point in time. The idea generation often led us into the unknown field. I realised that having good knowledge of how common things works (from simple ball pen to sophisticated electronic equipment) is very helpful in the generation of

ideas. Engineering students tend to solve problems from a technical viewpoint and ignore users' experience. Through design thinking, I have learnt how to appreciate both knowledge and use them together to solve problems. The impression I had on design thinking is that, in today's context, making a product is no longer just to satisfy the intended application or functions of the product but to satisfy the users' experience".

[Enrico Aeria]: "I think infusing design thinking into an Engineering project is useful and can be methodical. It encompasses all aspects of a product, making sure that every aspect is thought through. However, a problem that could arise from design thinking is the fact that there could be an overwhelming amount of details and so many aspects to look into that it can get rather tedious initially. In addition, design thinking generates so many radical ideas that sometimes it may be hard to carry it out in terms of current state of arts and social norms. I think the design thinking philosophy is a great approach towards creating a new product. Occasionally, it helps reveal problems that might be possibly encountered in the future. This gives the ability to come up with a solution earlier on and think of alternative ways. Design thinking revolutionizes products and makes them different, unique and interesting".

From the students' feedback and the author's observation during the 30 weeks (excluding vacation) long capstone project, the following issues were identified and discussed:

1. Students were generally appreciative of DT but were worried about DT activities encroaching into their Engineering activities. DT activities were perceived as "extra works" when compared to engineering activities.
 - The students spent about 3 weeks on DT activities. This was partly due to the fact that they were not trained in DT methodologies. Extra lessons were needed to cater for all "pioneer" batches of DT final year project students. It is advisable that DT activities should be intensive and within a timeframe of not more than 2 weeks. If situation permits, ethnography can be carried out during vacation just before the beginning of new semester. The current CDIO assessment rubric for final year projects in the school does contain some features that mitigate the wide spectrum of projects undertaken by difference groups. For example, marks for the Conceive and Design stage can be adjusted with higher weightages by the supervisor and co-examiner. Nevertheless, a separate rubric for DT engineering projects would be perceived to be a fairer assessment scheme which could alleviate students' anxiety.
2. Students were also concerned that faculty members assessing them may not be well versed with DT methodologies resulting in their grades being adversely affected.
 - DT projects with its high demand in exploring consumer desirability should not be treated as another engineering project. Only supervisors who are trained in DT should supervise or co-examine the project group. Number of DT engineering projects must be managed. Dym et al. (2005) concludes that for long term sustenance of cornerstone and design courses, "there is a clear need to expand the number of faculty members interested in and capable of teaching design, and to create the facilities such as design studios and associated shops needed for modern, project-based design courses". At the moment, the School of Mechanical and Aeronautical Engineering has trained almost 50% of its staff on DT literacy. This has been achieved by way of workshops, seminars and clinical sessions.
3. Engineering students generally find difficulties articulating the emotional aspect when empathizing with users during their field trip.
 - For example, when the team were asked to categorise the issues into "SPEC"-Social, Physical, Emotion and Communication; none were found

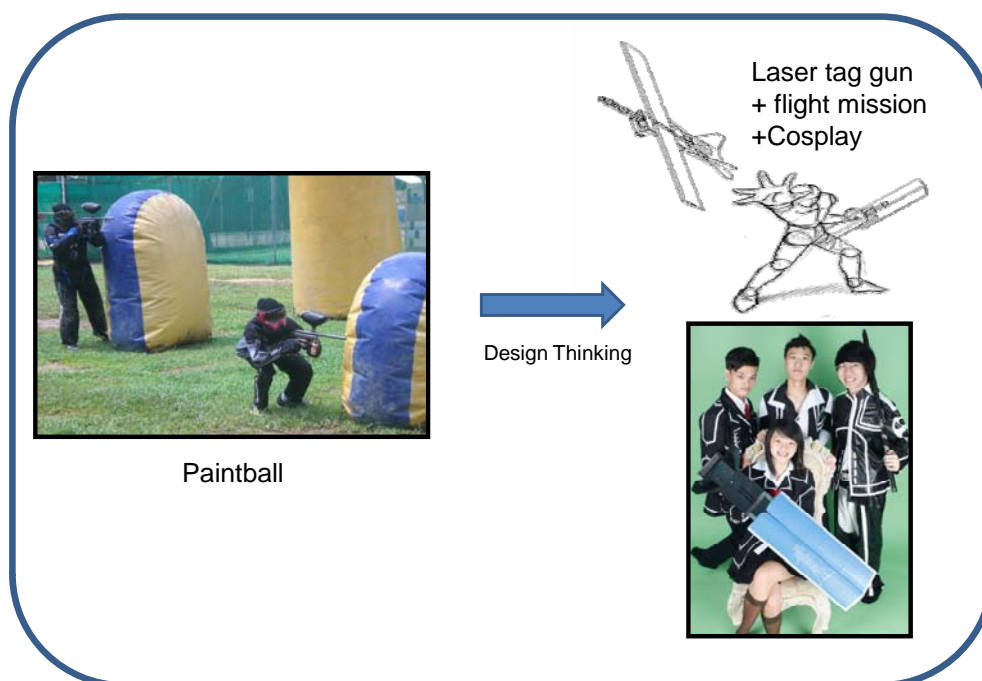
under the “Emotion” category. In the “Toy Gun” project, the supervisor had to change the “Emotion” into the “Environment”. Exposing students with DT concepts using cornerstone projects before proceeding to a capstone projects could be useful in equipping students with the “correct” mental attitude. A new course structure has been revamped to include DT content in the Introduction to Engineering module. On a social level, such inability to discern emotional elements could be linked to the general characteristics of the so called “Generation Y” and not just confined to engineering students. More studies may be needed to establish a correlation.

4. Tendencies for engineering students to think “within the box”.
 - In course of project, it became clear that students had a strong tendency to use their “expert” knowledge to solve an open ended problem. For instance, while brainstorming for a unique toy gun gaming concepts, the aeronautical students suggested developing a toy gun capable of flying as part of the mission in the game. This was followed by a strong bias among team members during voting of various concepts. Using “expert” knowledge is not wrong in itself. Nevertheless, project supervisors should be mindful to steer the team, based on human centric approach. Forming a project group comprises of team members from different schools (i.e. multidisciplinary) is another way to force an “out of the box” thinking. In fact, this is a preferred setting in running a DT project. However, administrative issues such as uniform marking scheme, funding procedures, rapport, interest, school cultures etc have to be properly considered and managed.

5. DT process may end up with non-engineering solutions.
 - Establishing the scope of a DT capstone project in the context of Engineering may not be straight forward. If the project is not well guided, it might end up with non-engineering (sometimes trivial) solutions. One might argue that to be truthful to DT, project supervisors should not interfere with the nature of the outcomes. However, it seems proper to steer engineering students towards engineering solutions because first of all, a capstone project provides an excellent platform for engineering students to put in practice the engineering theories they have gained from classroom learning. Secondly, as Armstrong et al (2005) has pointed out, “capstone project was felt to have the greatest potential for addressing a significant number of the CDIO Standards in a single initiative”. Thirdly, engineering students generally feel motivated doing “relevant” activities. Furthermore, allowing development of engineering products by using DT methodologies helps to convince engineering students how DT could complement and enhance engineering product development. Hence, it becomes an art for the project supervisor to return an “off-tracked” team back to the engineering path “naturally”. One technique is to declare at the onset, that the main outcome is to develop physical products. The author would usually ask engineering students to innovate on ordinary products with no details provided in order to maintain a level of fuzziness and students were left to “realise” their own design briefs or problem statements.

CONCLUSION

Design Thinking has the potential to provide learning opportunities for engineering students to explore human desirability, technical feasibility and business viability. With CDIO being the context of our education, infusing Design Thinking into CDIO framework has many challenges. Most pressing issue is students' and staff's DT literacy. Engineering students generally feel uneasy working on open ended projects where they are responsible in defining their own project scope. Dym et al. (2005) highlighted that "the real challenge is not the adoption of the principles of divergent-convergent inquiry; rather, it is the integration of divergent-convergent inquiry into the existing engineering curricula". While it may seem easier to infuse DT into capstone projects, earlier exposures are needed for effectiveness. Existing cornerstone projects in the "Introduction to Engineering" module and "Design and Build" module appear to be able to provide windows of opportunities, to train engineering students in DT literacy.



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CDIO Syllabus Survey: Systems Engineering an Engineering Education for Government

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ABSTRACT

During the spring of 2010, approximately 300 hiring managers working for the US Navy participated in the CDIO survey sampling the desired engineering skills and proficiencies for their workforce of over 30,000 scientists and engineers. The survey results will support engineering education reform initiatives spanning engineering schools across the country, particularly those in which the Navy directly invests. Sponsors sought an opportunity to send a clear “demand signal” to the academic community to promote engineering education reforms and help them align their programs with projected workforce needs. This application is novel in several regards. First, the survey collected data spanning a very large government agency employed in the development of high technology systems. Secondly, data was sought regarding the desired attributes of both new-hires, direct from undergraduate programs, and mid-career individuals, to better distinguish the attributes sought from graduate programs serving the US Government. Finally, adaptations of the traditional CDIO survey method were implemented, several of which were beneficial, yielding interesting results, and at least one which was problematic.

KEYWORDS

CDIO survey, graduate attributes, government engineers, industry stakeholders

BACKGROUND

The US Navy expects to hire 4-5% of all engineers graduating from U.S colleges and universities over the next several years, principally into civilian jobs in systems development. Hence, the Navy will likely be the nation’s single largest employer of new engineers, and a dominant stakeholder in engineering education curriculum and standards for the foreseeable future. Just as engineering enterprises expect their customers and stakeholders to help them understand their requirements, engineering organizations have a responsibility to ensure that their requirements are known and understood by the nation’s engineering schools.

A little background emphasizes the importance of this activity. In the mid-90s, accreditors charged U.S. engineering schools with re-orienting their programs to ensure student competency in traditional engineering science subjects, as well as in “soft skill” areas like teamwork, communication, and successfully working in modern engineering enterprise organizational models. Accreditation criteria deliberately provided institutions with latitude regarding the relative importance of these additional skills, directing institutions to act in concert with their stakeholders to identify institutional emphases. Unfortunately, the intended reforms largely stalled short of the original goal due in part to a lack of clear stakeholder direction and engagement– success has been hindered by an incomplete/unclear demand signal. ASEE’s recent study, *Creating a Culture for Scholarly and Systematic Innovation in Engineering Education*, charges industry to increase its connections with Education and explicitly support curriculum development: “Encourage engineering line personnel to

participate in benchmark surveys, serve as adjunct faculty, and other activities that connect line personnel with engineering programs.” [1]

In recognition of this “demand signal shortfall”, the Education committee of the Navy’s Chief Engineers commissioned a survey of Navy Systems Command (SYSCOM) engineers and leaders to gain insight on the professional expectations and career progression of Navy engineers, as well as an understanding of the role of formal education in their development. The Department of the Navy’s five engineering SYSCOMs provide the total life cycle development, acquisition and engineering support. The Naval Sea Systems Command (NAVSEA) procures and supports ships and shipboard systems. The Naval Air Systems Command (NAVAIR) procures and supports aircraft and aerial weapons. The Naval Facilities Command (NAVFAC) provides shore base infrastructure engineering and maintenance. The Naval Space Warfare Command (SPAWAR) procures and supports space assets and fleet communications. The Marine Corps Systems Command (MARCORSYSCOM) procures and supports ground equipment for the US Marine Corps.

According to Jesse McCurdy (AIR-4.0A), chief civilian engineer for the Naval Air Systems Command, “The reforms intended by ABET 2000 appear to have stalled... Industry bears a large part of the responsibility, for want of a clear, persistent demand signal. Industry then bears the cost, as we must then complete the education necessary for engineers to contribute in today’s enterprise.”[2] Engineering education is changing, but not at the pace required by industries daunted by the well-publicized graying of their engineering workforce. [3, 4] The U.S. Navy is among the largest of those enterprises.

Vacancies created by baby-boomer retirements, and President Obama’s direction to rebuild the government’s acquisition workforce, compel the Navy to hire almost 3,000 engineers per year over the next several years. Of those, 800 will be commissioned officers, 400 each from the Naval Academy and civilian campuses. The systems commands seek three times that number for civil service positions performing research, systems development, acquisitions, test and evaluation, and maintenance support. Most of those jobs entail the newest of new technologies; some find new ways to keep old ships afloat.

“Consequently, the Navy’s a dominant stakeholder in engineering education curriculum and standards for the foreseeable future. Just as we expect our customers and stakeholders [the fleet] to help us understand their requirements, we have a responsibility to ensure that our requirements are known and understood by the nation’s engineering schools.”[2] As most complex engineering projects should begin with a clear identification of customer requirements, engineering the engineering education should likewise begin with defining the desired product attributes, in this case the new-hire engineer.

The U.S. accrediting body, ABET, together with industry, initiated this reform of undergraduate engineering education in the mid 90s with a shift to an outcome based assessment (student learning), in lieu of measuring inputs (budgets, student-to-faculty ratios, syllabi). Programs are tasked to establish program objectives with their stakeholders, against which program success is to be measured and improved. Requirements continue to seek student competency in traditional engineering science subjects, but with a heightened emphasis of “soft skill” areas like teamwork, communication, and successfully working in modern engineering enterprise organizational models. These professional skills requirements appear as “ABET criterion 3, a through k.” Programs are required to demonstrate that their graduates have acquired:

- a) an ability to apply knowledge of mathematics, science, and engineering
- b) an ability to design and conduct experiments, as well as analyze and interpret data

- c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- d) an ability to function on multi-disciplinary teams
- e) an ability to identify, formulate, and solve engineering problems
- f) an understanding of professional and ethical responsibility
- g) an ability to communicate effectively
- h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- i) a recognition of the need for, and an ability to engage in life-long learning
- j) a knowledge of contemporary issues
- k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Note that these describe undergraduate program objectives because the undergraduate degree is the terminal degree required for licensure as a Professional Engineer in the United States.

Accreditation criteria deliberately provided institutions with significant latitude regarding the relative importance of these additional skills, directing institutions to act in concert with their stakeholders to identify particular institutional and program emphases. While latitude is delegated to programs to determine the relative emphasis, no mechanism is suggested and many programs furthermore find the guidance and criteria lacking sufficient detail for program design.

THE CDIO SURVEY INSTRUMENT

CDIO stands for Conceive, Design, Implement and Operate, and hence expresses the theme of designing engineering education around the theme of the product life cycle. CDIO attempts to systems engineer the engineering education.

Figure 1 depicts the foundational goal of the CDIO initiative.[5] Engineering faculty members from the first half of the last century typically brought industry experience into academia. The progressive advancement of the engineering sciences crowded the professional skills of the engineering workplace out of both the faculty and the curriculum, as the unintended consequence of warranted improvements in scientific rigor. Today, improvement in both axes warrants reform of the design of engineering education programs and faculties.

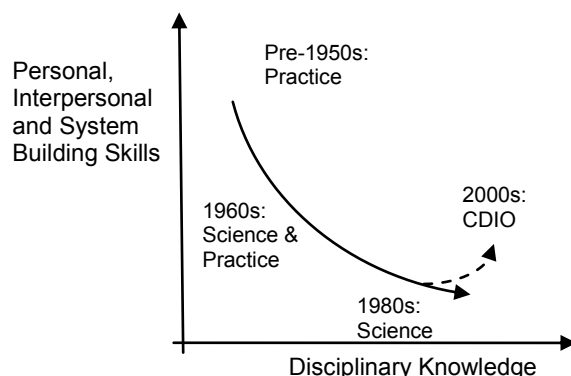


Figure 1. Evolution of Engineering Education

In 2000, MIT joined with three Sweden universities to publish the CDIO syllabus, as a general template for undergraduate engineering education which was then vetted internationally by both academia and industry. Crawley demonstrated that the CDIO syllabus

satisfies all of the criteria of ABET 2000, providing more detail while amplifying the industry-desired skills not captured in criterion 3(a-k).[5] In some countries, such as Sweden, the CDIO syllabus has since been embraced as the construct for all engineering accreditation. The syllabus has since seen one substantial revision, in 2010 [6]. The syllabus has seen significant U.S. endorsement recently, from NAE President Charles Vest and past-ASEE president Sherri Shepherd, as well as major direct support from defence sector corporations such as Boeing, General Electric, Lockheed-Martin, Orbital Sciences, and Raytheon.

US Navy involvement began in 2003 when the Naval Academy's Aerospace Engineering program embraced the CDIO syllabus, motivated by several reasons:

- 1) the syllabus well described the kind of work done by USNA graduates who enter Navy SYSCOMs;
- 2) the syllabus, through a survey instrument, provided a direct means for stakeholder priorities to be identified as program design requirements;
- 3) the syllabus provided a model for flowing program objectives down to course content and activities; and
- 4) the syllabus's scope compelled embracing contextual engineering education, whereby technical skills and knowledge are developed simultaneously with professional skills such as communications and teamwork.

The USNA Aerospace Engineering program reorganized around the CDIO construct in 2003. Consequently, the survey was then administered to a limited set of aerospace stakeholders in NAVAIR, NASA and industry, with about 20 total respondents, resulting in program adoption and redesign. In the recent several years, programs within many prominent U.S. engineering colleges have embraced the CDIO framework, including Duke, Penn State, Georgia Tech, University of Michigan, Purdue, Embry-Riddle, Stanford, and the Naval Postgraduate School, each of which contribute substantially to the Navy workforce.

At the second level of detail, the CDIO syllabus captures the following desired student skills.

Table 1. CDIO Skills (Level 2)

1. Technical knowledge and reasoning
 - 1.1. Knowledge of underlying sciences
 - 1.2. Core engineering fundamental knowledge
 - 1.3. Advanced engineering fundamental knowledge
2. Personal and professional skills and attributes
 - 2.1. Engineering reasoning and problem solving
 - 2.2. Experimentation and knowledge discovery
 - 2.3. System thinking
 - 2.4. Personal skills and attitudes
3. Professional skills and attitudes
 - 3.1. Interpersonal skills: teamwork and communication
 - 3.2. Teamwork
 - 3.3. Communications
4. Conceiving, designing, implementing and operating systems in the enterprise and societal context
 - 4.1. External and societal context
 - 4.2. Enterprise and business context
 - 4.3. Conceiving and engineering systems
 - 4.4. Designing
 - 4.5. Implementing
 - 4.6. Operating

The syllabus has four levels of detail [6], identifying the desired skills of graduating engineers across the full spectrum of their work lives, and providing stakeholder ratified requirements to

specific programs, via a survey instrument, based on the peculiar work demands of those stakeholders. Navy SYSCOM engineers and leaders recognized and affirmed the value of these skills in our workplaces. Though, these listed skills are not equally critical, nor would we expect their development to be uniform at the point of hire. Furthermore, organizations will continue to develop each requisite skill once an engineer joins a team and works in particular contexts. Several of these skills will mature only over several decades of work.

In recognition of this “demand signal shortfall”, the Systems Engineering Education Committee of the Navy’s Systems Engineering Stakeholders Group commissioned an effort to survey SYSCOM engineers and leaders to gain insight on the professional expectations and career progression of Navy engineers, as well as an understanding of the role of formal education in their development. In 2010, approximately 300 hiring managers participated representing NAVAIR, NAVSEA, NAVFAC, SPAWAR and MARCORSYSCOM. The survey results sought to support engineering education reform initiatives spanning engineering schools across the country, particularly those in which the Navy directly invests. This was a hoped for opportunity to send the Navy’s “demand signal” to the U.S universities to influence their engineering education reforms and help them align their programs with their projected workforce needs.

The survey and syllabus was designed by a international consortium of engineering schools, led by Professor Ed Crawley from the Aero/Astro department at MIT, and is meant to be applicable to all engineering disciplines [4]. In the CDIO’s consortium’s baseline survey, as administered by several dozen institutions, stakeholders are asked to rate the desired proficiency of new-hire engineers on a five-point scale, in each of the CDIO skill areas. Some programs conduct this survey solely at level-2 on the scale, and others conduct the survey at level-3. The five point scale is:

1. To have experienced or been exposed to (minimal experience/limited exposure)
2. To be able to participate in and contribute to (some familiarity/ability to participate and contribute)
3. To be able to understand and explain (knowledgeable/experienced enough to understand and explain)
4. To be skilled in the practice or implementation of (skilled in the practice or implementation)
5. To be able to lead or innovate in (capable of leading and/or innovating)

In the graphics below, these five levels will be represented by “Exposure”, “Contribute”, “Explain”, “Practice”, and “Lead & Innovate.” Commonly, respondents have been asked to rate themselves in each skill, prior to rating the desired new hire. This has been shown to provide a calibrating effect on the results, calming the tendency to inflate the desired skill level of the new hire.

The SYSCOM survey reported below modified MIT’s baseline survey in three ways, in hopes of further refining the clarity of the information to engineering program architects. First, respondents were also asked to rate the desired skill levels at four career marks, vice the two typically asked, to now include the new high school graduate and the mid-career engineer, as well as the new hire and the senior executive engineers. The high school data was requested by SYSCOM leaders responsible for K-12 outreach. It was therefore possible that for some skills, no exposure would be warranted prior to undergraduate matriculation, and the option was provided for “No prior exposure,” a feature not present in prior surveys. The mid-career data was sought by those funding graduate school programs. Secondly, respondents were additionally asked to identify whether they thought the particular skill would be best developed in an academic or work environment. Finally, the survey queried the workplace demand for various mathematical skills.

The survey spanned solely the 2.x, 3.x and 4.x skills, which represent the y-axis (ordinate) of Figure 1 above, omitting the 1.x technical skills. This permits the results to be generalized to the work of any engineering discipline (e.g. Electrical, Mechanical, Chemical). Furthermore, professional skills such as writing, should not be viewed as prioritized against the fundamental technical studies, but a separate dimension pursued in concert with the technical skills. Advocates of such contextual learning have demonstrated that both professional and disciplinary can be developed simultaneously through integrated learning experiences that are deliberately designed with such goals.[6]

RESULTS

Survey Demographics

Tables 2-6 characterize the survey's respondents. Note that some columns total greater than 100% because some respondents responded 'yes' to more than one category (e.g. masters and PhD, or test pilot school plus a masters degree). These results should not be presumed to represent the demographic of these commands, but simply characterize survey participants. The Naval Air Systems command participated more strongly than others, attributable to its leadership's strong personal appeal. Results later show little variation between the commands. Hence this imbalance does not compromise the validity of our findings. In general, survey participants were middle-to-late career engineers, slightly less than half of whom held post-graduate degrees in science and engineering. A similar number had additional education in business or administration, with 22% holding degrees in these fields. The 30% who have business or management course work short of a degree are likely attributable to the congressionally-set educational requirements for acquisition professionals, such as certificate programs in Systems Engineering and Program Management.

Table 2. Parent Command

NAVAIR	71%
NAVSEA	23%
SPAWAR	4%
NAVFAC	4%
Other	1%

Table 3. Respondent Career Band

Early career (<10 years since Bachelor's degree)	3%
Mid-career	40%
Late-career (>25 years since Bachelor's degree)	57%

Table 4. Respondent Undergraduate Degree

Mechanical Engineering	15%
Civil Engineering	4%
Electrical/Computer Engineering	31%
Aerospace Engineering	13%
Naval Architecture/Ocean Engineering	1%
Computer Science/ IT	6%
Industrial Engineering	3%
Other science or engineering	21%
Neither a science nor engineering undergraduate degree	4%

Table 5. Respondent Postgraduate Education

No post-graduate education in these fields	35%
Some post-graduate education in these fields	21%
Test Pilot School or comparable professional program	7%
Masters Degree in Engineering	30%
Masters Degree in Science or Math	8%
M.D./D.V.M.	0%
Ph.D./ Dr. Eng/ Sc.D.	4%

Table 6. Postgraduate Education in Business and Administration

No formal education in these fields.	52%
Some formal education short of a M.S. (e.g.- DSMC)	26%
A Masters in business or administration	22%
A PhD in business or administration	0%

Desired Proficiency Results

The bulk of the survey asked respondents to rate the desired proficiency of engineers at four stages in their development: graduating from high school, new hire, mid-career, and senior engineering team leadership (executive). Results are depicted in Figure 2 for each of those four stages.

One of the first questions was whether a significant difference could be identified between the expectations of hiring managers in the Navy's diverse systems commands. Diamonds indicate the response of NAVAIR managers; asterisks depict NAVSEA responses, and the boxes depict that of the other commands whose sizes are much smaller. The solid line depicts the averaged response of all respondents. Due to the similarity of the work, it's not surprising that no significant difference is noted between the responses from NAVAIR and NAVSEA. The responses of the other systems commands are biased lower. The results identify educational program priorities; consequently, the relative level of various skills is more important than their absolute value. Since the shape of the curves from the other commands follows the NAVAIR and NAVSEA priorities, the commands can be considered to be looking for identical relative distribution of skills. Hereafter, the averaged desired proficiencies will be considered as representing the coherent Navy demand.

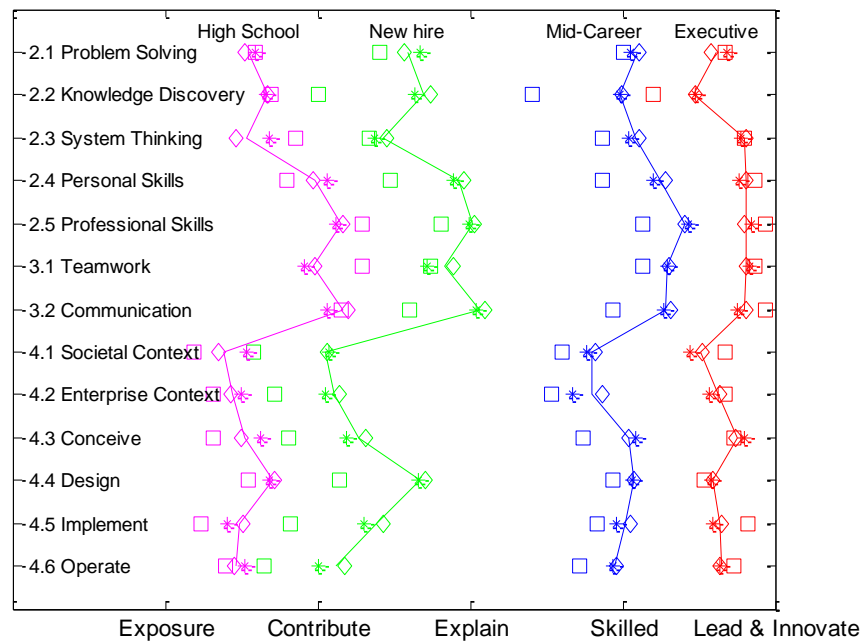


Figure 2. Desired Engineering Skill Proficiencies

The data exhibited almost uniform standard deviations across all skills and career levels (\pm one skill level). The uniformity suggested uniform confidence in the applicability of scores, and that data is omitted.

Figure 3 rank-orders the skills for the new-hire and mid-career engineer, the two bands of interest to engineering educators. Undergraduate program leaders should note the prominence of skills such as Communication, Personal and Professional Skills, Teamwork and Knowledge Discovery. Undergraduate program design must account for the purposeful development of these skills if they're to suitably equip students for contribution to this workforce.

Similarly, graduate program leaders should note the prominence of teamwork and communications, skills not commonly emphasized in an engineering masters degree. Shifts in emphasis between the new-hire and mid-career engineer are also interesting, with three skills promoted significantly between these two benchmarks: Teamwork, Problem Solving and Systems Thinking. Hence the market demand for mid-career development signals areas that may deserve heightened emphasis in graduate programs seeking to serve this constituency.

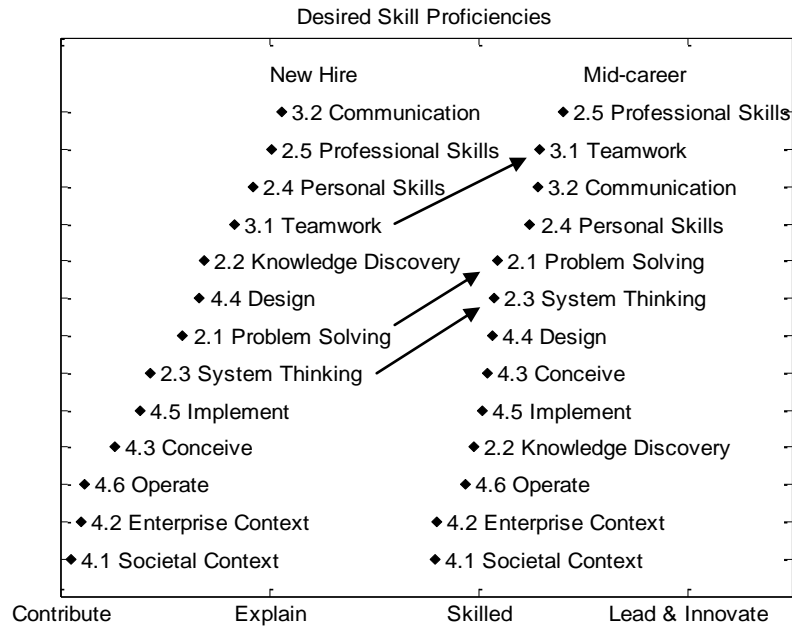


Figure 3. Rank-ordered Engineering Skill Proficiencies

Skill Development Locus

As a correlating measure, the survey asked where respondents expected the mid-career engineer to have developed each of the CDIO skills. The goal was to assess the locus where managers expected development to occur. The results depicted in Figure 4. The center diamond indicates the average of respondents' answers, and the bar indicates ± 1 standard deviation. Importantly, none of the skills will be matured in solely an academic or work context, implying an expectation that *every* skill should receive at least some exposure in academic setting, while recognizing that *every* skill will be further matured in the work setting. Second, only two skills appear to the left of the center, 'Knowledge Discovery' and 'Communication', indicating that there's a strong expectation that educational programs will place significant emphasis on these skills. "Design" appears barely right of the meridian, indicating that hiring managers likewise expect new hires to have substantially been exposed to design prior to entering the government workforce. An alternative explanation is that design skills aren't typically matured in the context of the SYSCOMs' work. The prior results rebut this interpretation, given the high expected design competence of mid-career and executive level engineers.

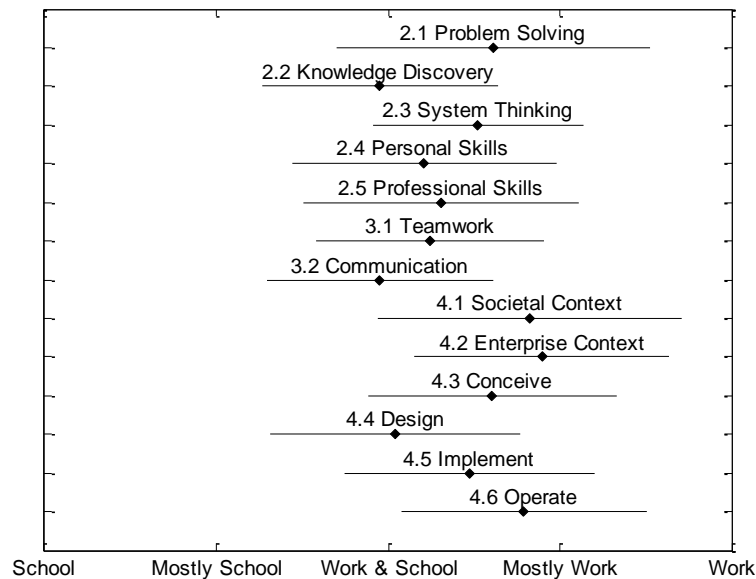


Figure 4. Skill development locus

Those skills have been reordered in Figure 5 in descending order of the emphasis for academic institutions. As several natural breaks occurred, the skills were grouped as “deserving focused academic emphasis”, “deserving deliberate academic development”, and “deserving academic exposure”. The emphasis is reassuringly similar to the skills that floated to the top of our rank-ordered skills from Figure 3.

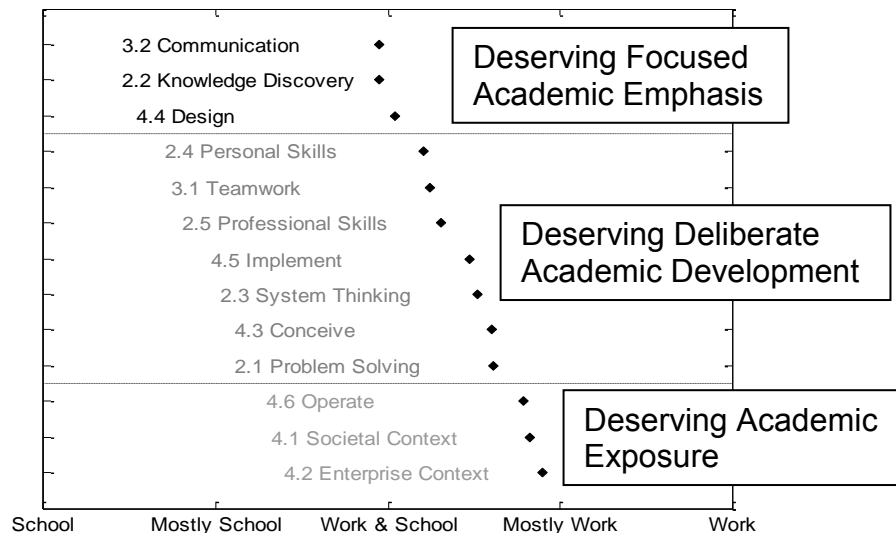


Figure 5. Skill development locus

Mathematics Competency

Engineering faculty routinely bemoan the mathematical proficiency of today’s engineering students, which they perceive to have slipped significantly over recent decades. A variety of causes are attributed in the literature, to include premature placement in calculus while in

high school, and a premature or over-reliance on technological tools (such as advanced calculators) [1].

Survey respondents were asked to rate the frequencies with which particular math domains are utilized in their SYSCOM workplace. Results are depicted in Figure 6, the diamonds indicating the average across all respondents, and the horizontal bar indicating the standard deviation. Probability and statistics lead the list, a topic typically required only by EE undergraduate programs. The foundational domains of calculus and differential equations appear last on the list. A glance at the ME, EE and Aero programs of eight prominent East Coast engineering schools revealed that $\frac{3}{4}$ of those 24 programs require a programming course; $\frac{1}{2}$ require courses in Probability and Statistics; $\frac{1}{2}$ require linear algebra; and only $\frac{1}{4}$ require numerical methods.

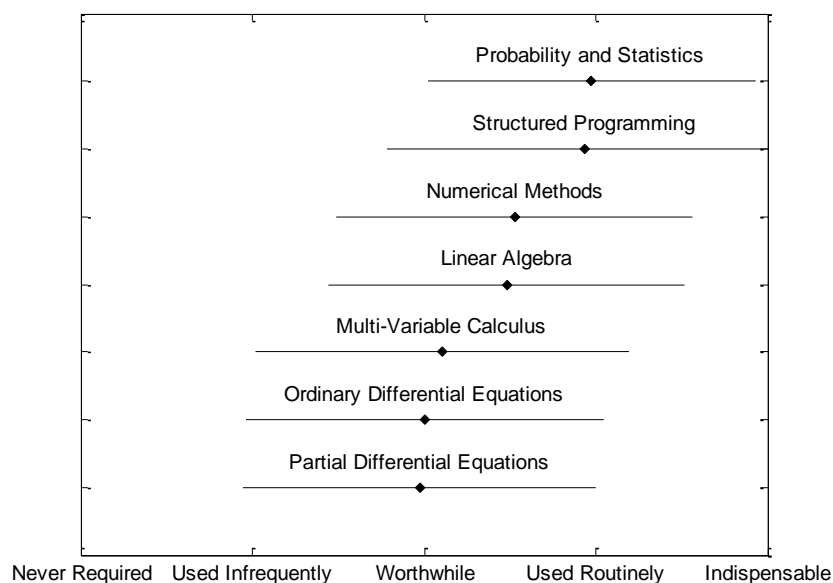


Figure 6. Workplace Dependence on Math Skills

The design space for undergraduate engineering programs is very tight, and other demands have squeezed “advanced” math topics out of many programs. Calculus and ordinary differential equations (ODEs) are considered foundational for the study of both physics and most engineering science, and hence ubiquitous, yet survey respondents indicate that those skills are the least commonly used in the workplace. Some undergraduate programs require one additional semester of math, beyond the four semesters of calculus and ODEs, yet those other topics appear most likely to be used in the Navy’s engineering workplace, and the choice might be left to the student. Consequently, programs serving Navy engineering organizations at the undergraduate and graduate level should ensure engineering students have the opportunity for formal mathematics beyond the basic four semester calculus/ODE sequence, and that the application of math to upper-level courses emphasizes those skills that managers indicate will be most used in their workplace.

Survey Mechanics

Conduct of the CDIO survey in other settings asked respondents to grade the desired proficiency of both their respected peers and new hires. We and others had found that asking respondents to first assess their peers had the desirable effect of calibrating respondents so

that they did not inflate the desired attributes of new hires. Once they candidly admitted they themselves were not '5' down the list, a reasonable score would result for the new hire.

In this edition of the Syllabus Survey, other stakeholders asked for two other benchmarks, the post-secondary student and the mid-career engineer. The proficiency score of "0: no exposure" was added to permit the post-secondary student to be graded at that level for some skills. After the survey was complete, we realized that we had asked respondents to characterize four career milestones using a scale with only 6 possible increments. The insertion of another career milestone above and below the new-hire appeared to bound the new-hire results, such that the highest scores were not as high, nor the lowest scores as low, as those observed in previous editions of the survey conducted by USNA with a similar constituency, albeit smaller. For example, the highest rated skill, "Communications" dropped from a competency level of 3.4 to 3.1. Conversely, the lowest ranked skill, "External Context", rose from a score of 1.6 to 2.0. Significantly, the ranked order of skills changed very little, with Figure 2 above capturing almost the identical order observed in the 2003 survey conducted by USNA Aerospace. Consequently, we do not believe that the scores can be legitimately compared with other editions of the CDIO Syllabus Survey, as conducted by other institutions, or our own legacy results. The post-secondary results proved of little value and should not have been solicited; they diluted the value of the primary study concern and added to the respondent's effort. The mid-career data is of interest, and yielded worthwhile insight. If it's to be repeated by other institutions, they should allow for a half-point scale. Importantly, since the application of the data is principally in the relative emphasis received in an academic program's design, the above defect does not invalidate the survey's use in rank-ordering a curriculum's targeted skills, as we've done above.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions apply to undergraduate engineering programs serving the Department of the Navy. Foremost, soft skills development such as communications and teamwork rank in criticality with traditional technical skills such as problem solving, and deserve similar focused attention. Second, the survey results point to appropriate weighted emphasis for program design. Visiting committees, program administrators, and institutional leadership should ensure their program design addresses the demand signal represented by these results. Finally, most programs neglect the math skills development that supervisors indicate are most commonly applied in their workplaces. Departments should openly deliberate program mathematics requirements in light of the above findings.

The following conclusions apply to graduate programs serving the Department of the Navy. First, the survey affirms the importance of research and project work, as captured by the high rating assigned to Knowledge Discovery. This affirms traditional elements of graduate level study, such as thesis research or capstone design experiences. Of import however, many skills not emphasized in graduate programs deserve pointed emphasis to include the non-traditional elements of communications, teamwork, and systems engineering. These two are also sought from the Masters experience, with academic development complementing the workplace development of these skills.

Results of this study are not necessarily generalizable to other large engineering enterprises, but may be representative of the needs of government engineering agencies worldwide whose work is paired with industry partners. The Navy's engineering workforce is engaged in work that's distinct even from their defence-industry partners. It does however represent the application of the CDIO syllabus survey to a very large engineering enterprise with a significant stake in US engineering education.

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DEVELOPING CRITICAL THINKING SKILLS THROUGH DYNAMIC SIMULATION USING AN EXPLICIT MODEL OF THINKING

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ABSTRACT

A major skill area of CDIO is Part 2.4 Personal Skills and Attitudes, which subsume skill sets relating to good thinking. This paper takes the position that critical thinking skills can be explicitly taught, much in the same way as other skills. Students need to clearly understand what good thinking actually entails, have opportunities for active and experiential application in real-world contexts, as well as receive clear and useful feedback from expert professionals.

In this paper, we firstly present our model of thinking, which has been derived from extensive review of the literature and our own research in cognitive modelling engineers as they solve real world problems. The model identifies the key types of thinking involved in such problem-solving as well as the cognitive processes involved. This provides a practical heuristic model of good thinking, which can be taught explicitly and used for purposes of assessing thinking.

Secondly, focusing on the chemical engineering context, we outline the various ways in which critical thinking skills can be effectively taught in a range of learning contexts and, in particular, dynamic simulation.

Thirdly, we present our research findings on the student learning experience in relation to the development of critical thinking skills from using dynamic simulation to solve chemical engineering problems. The research employs a rigorous qualitative methodology involving observation and in-situ and post activity questioning of student performance relating to solving problems. A broad phenomenographic approach was employed to identify the range of variation in student's cognitive approaches and heuristics when solving the problem scenarios presented. Some comparisons are also been made in terms of performance on simulated activities between student groups explicitly taught critical thinking skills and those not explicitly taught these skills.

The paper concludes with an optimistic frame on both the explicit teaching of critical thinking and the particularly useful role of dynamic simulation as an effective pedagogic tool for developing the range of critical thinking skills.

KEYWORDS

Critical thinking, dynamic simulation, chemical engineering, real-world tasks

INTRODUCTION

“Good thinking” (however defined) is a key attribute for successful learning. As Paul [1] outlined:

Thought is the key to knowledge. Knowledge is discovered by thinking, analyzed by thinking, organized by thinking, transformed by thinking, assessed by thinking, and, most importantly, *acquired* by thinking. (vii)

Similarly, Jenson [2] suggested that:

The best thing we can do, from the point of view of the brain and learning, is to teach our learners how to think (p.163)

However, recognition that certain internal cognitive processes – ‘thinking’ – make a substantive difference, beyond those of memorization, to understanding and application of acquired knowledge, does little in itself to aid systematic development of such capability in our students. Without sufficient valid definition of what constitutes such terms as ‘critical thinking’, ‘creative thinking’ – indeed, ‘good thinking’ – teaching faculty will find difficulty in teaching and assessing these desirable cognitive skills.

There are no shortage of models of thinking or lists of thinking skills, processes and dispositions (e.g., Marzano [3]; Swartz & Parks [4]; Perkins [5]). Similarly, there seems to be a reasonable agreement that competence in ‘thinking’ can be developed through appropriate pedagogic strategies. How we have learned to think will determine in large part how we think, much the same as for any kind of learned activity. As Perkins [6] points out “People can learn to think and act intelligently.” (p.18) Paul [1] provides an interesting analogy between the development of mind and physical fitness. He points out that the mind, like the body, “has its own form of fitness or excellence” which is “caused by and reflected in activities done in accordance with standards (critically)” (p.103). He goes on to argue that:

A fit mind can successfully engage in the designing, fashioning, formulating, originating, or producing of intellectual products worthy of its challenging ends Minds indifferent to standards and disciplined judgment tend to judge inexactly, inaccurately, inappropriately, prejudicially. (p.103-4)

However, the problem for curriculum planners and teaching faculty is to decide what exactly they are to include as *thinking* when planning courses and teaching thinking.

We introduced an explicit model of thinking that has proved useful both for planning curriculum activities to develop skill in thinking and assessing its application in real world engineering problem-solving. It does not profess to capture all aspects of this elusive cognitive capability; which is an unrealistic goal in the present context. However, we feel that it is sufficiently valid in terms of broad classification of types of thinking and the typical heuristics involved offer a useful base for the development of good thinking in students.

AN EXPLICIT MODEL OF THINKING

As indicated above, accurate conceptualization of internal cognitive processes (e.g., thinking) is problematic and hence likely to be unreliable, especially across subject domains. However, research suggests that while there is variation in how humans experience phenomena in the world - based on prior experience and selective perception, etc - our common human apparatus and need orientation typically results in shared ways of experiencing the world. Indeed, without this commonality, the inter-subjectivity of everyday

life would be even more problematic than it is already. For example, Marton [7] points out that:

...we have repeatedly found that phenomena, aspects of reality, are experienced (or conceptualized) in a relatively limited number of qualitatively different ways. (p.181)

What this means is that while psychologists may solve problems in some qualitatively different ways from chemical engineers, both at the individual and collective level, there is much of similarity in the types of cognitive activity involved. For example, they will need to analyse situations (cases), make comparison and contrast with similar cases, build up inferences and interpretations from ongoing perceptions and data accumulation, generate possible solutions and decide action based on chosen criteria. Around this swirl of cognitive activity, there will be an overall monitoring of what is going on – typically referred to as metacognition. The explicit model of thinking used in the context of this paper depicts six main types of thinking as shown in Figure 1.

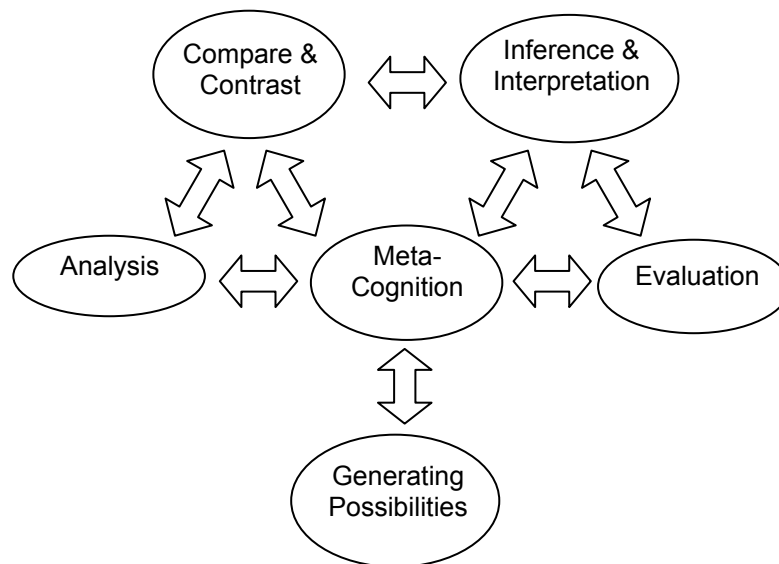


Figure 1: A Model of Types of Thinking

Table 1 summarizes the key heuristics that underlie these broad classification frames on different types of thinking.

Table 1
Summary of Key Heuristics of Types of Thinking

<p>Generating Possibilities</p> <ul style="list-style-type: none"> • Generate many possibilities • Generate different types of possibilities • Generate novel possibilities
<p>Compare & Contrast</p> <ul style="list-style-type: none"> • Identify what is similar between things - objects/options/ideas, etc • Identify what is different between things • Identify and consider what is important about both the similarities and differences • Identify a range of situations when the different features are applicable

<p>Analysis</p> <ul style="list-style-type: none"> • Identify relationship of the parts to a whole in system /structure/model • Identify functions of each part • Identify consequences to the whole, if a part was missing • Identify what collections of parts form important sub-systems of the whole • Identify if and how certain parts have a synergetic effect
<p>Inference & Interpretation</p> <ul style="list-style-type: none"> • Identify intentions and assumptions in data • Separate fact from opinion in data • Identify key points, connections, and contradictions in data • Make meaning of the data/information available • Establish a best picture to make predictions
<p>Evaluation</p> <ul style="list-style-type: none"> • Decide on what is to be evaluated • Identify appropriate criteria from which evaluation can be made • Prioritize the importance of the criteria • Apply the criteria and make decision
<p>Meta-Cognition</p> <ul style="list-style-type: none"> • Aware that we can think in an organized manner • Actively thinking about the ways in which we are thinking • Monitoring and evaluating how effective we are thinking • Seeking to make more effective use of the different ways of thinking and any supporting learning/ thinking strategies /tools

In this model, analysis, compare & contrast, inference & interpretation and evaluation are typically employed during critical thinking; whereas generating possibilities, as the term implies, is predominantly in creative thinking. Metacognition is the overall monitoring of the other types of thinking with a view to enhancing overall effectiveness. In practice, these types of thinking run as overlapping and intertwined programmes, moving from foreground to background as the focus of a problem changes and certain questions arise. Certainly, when creativity is sought, generating possibilities is at the minds forefront, but other types of thinking will weave in and out of consciousness and, probably run continuously in the sub-conscious mind.

Furthermore, in the process of problem-solving, there will be the influence of personal beliefs, emotions and psychological state. The reality may indeed resemble that suggested by Apter [8]:

... everyday life, as it is experienced, is a tangled web of changing desires, perceptions, feelings, and emotions that filter in and out of awareness in a perceptual swirl. (p.33)

Similarly, Marcus [9], from a cognitive neuroscience perspective, fully highlights the challenge of achieving good critical thinking when he asserts that:

Our beliefs are contaminated by the tricks of memory, by emotion, and by the vagaries of a perceptual system that really ought to be fully separate – not to mention a logic and inference system that is as yet, in the early twenty-first century, far from fully hatched. (p.67)

Good thinking, from the standpoint of this paper, is the ability to navigate this “perpetual swirl”, and be able to employ the various heuristics of these types of thinking in a fluid, efficient and highly synergistic manner. This is perhaps the reason that good thinking is quite rare in many situations, and why we really need to teach it to our students.

It is in this context that writers in the field see critical thinking not just in terms of cognitive processes and technical standards but also in terms of the development of intellectual traits and standards. For example, Paul et al [10] identify the following traits as central to acquiring a high level of expertise in critical thinking:

- Intellectual humility – sensitivity to own biases and the limitations of knowing
- Intellectual courage – prepared to question own beliefs and those of others, even if unpopular with dominant perspectives and people
- Intellectual empathy – awareness of need to actively entertain different views from one’s own
- Intellectual integrity – holding oneself to the same intellectual standards of others (no double standards)
- Intellectual perseverance – working through intellectual complexities despite frustration
- Confidence in reason – recognizing that humankind’s interests are best served by giving free play to reason
- Intellectual autonomy – thinking for oneself in relation to standards of rationality and not uncritically accepting the judgements of others
- Fair-mindedness – conscious of the need to treat all viewpoints alike and be influenced by vested interests

Such dispositions are certainly desirable, but the extent to which some are more integral to deep seated personality traits is open to question, as is their successful development in a pedagogic context. However, they remain a regulatory ideal and as educationalists we do our best to encourage productive outcomes for our students. Carroll [11] summarizes the goal of critical thinking quite succinctly in terms of:

... guarantee, as far as possible, that one’s beliefs and actions are justifiable and can withstand the test of rational analysis.

CRITICAL THINKING IN CONTEXT OF CHEMICAL ENGINEERING

A particular challenge facing educators in chemical engineering is the inter-relatedness of various process variables. A typical chemical plant is made up of a number of unit operations in which various process parameters such as pressure, flow rate, composition, level, etc are being monitored and controlled. Often changes in one variable will have significant impact on other variables throughout the plant. Engineers and operators therefore need to have a thorough understanding of the inter-relatedness of the various variables to perform their tasks in a safe and efficient manner. This requires critical thinking in terms of being able to do effective and quick analysis, make appropriate inferences and interpretations as well as evaluate likely outcomes.

The development of critical thinking can be facilitated through a variety of active learning strategies that systematically cue such types of thinking. The good use of questions is particularly effective and efficient. Asking students to specifically analyse relationships, make comparisons and contrast, decide options, etc, focuses the mind on these types of thinking. Similarly, activities that require sustained engagement of such types of thinking, especially when dispositions that serve to enhance critical thinking such as open-mindedness and

perseverance are also encouraged. A particularly good approach is the use of dynamic simulation for a number of reasons, these include:

- providing a more authentic and motivating learning context for real world chemical processes than other school-based methods
- enabling a wide range of activities and complexity levels to be introduced strategically to progressively cue the full range of critical thinking skills and their underpinning cognitive heuristics, for example:
 - comparing and contrasting the differences in various process variables (temperature, level, pressure, flow rate, composition) in a chemical process plant resulting from a disturbance in stable operating condition or due to equipment malfunction
 - perceiving connections of the various observed phenomena, making accurate inferences and deriving plausible explanations of what had happened in the plant
 - inferring the best picture of what is happening in the plant, predict likely outcomes and evaluate consequences for possible actions taken
- facilitating the use of rapid and strategic feedback on student learning in which gaps in both thinking skills and knowledge domains can be rapidly ascertained and addressed in situ.

Dynamic Simulation in Context

In a nutshell, simulation is the construction and use of a computer-based representation, or model, of some part of the real world as a substitute vehicle for experimentation and behavior prediction. The central components of the simulation process are building the model (modeling) and running the model (i.e. the experiment). Broadly speaking, two types of simulation can be discerned, namely “static” (or steady state) simulation and dynamic simulation. By steady state simulation we mean that the modeled process is solved only for a specific set of operating conditions. This is like a snapshot of the process or operation. Any change in the operating conditions, requires re-solving the model. After converging, the model should predict where the process will settle. On the other hand, dynamic modeling will provide us with information about the process or operation over time. All variables are being “solved” at each time step and at any specific time we can monitor the operating conditions. Compared to the steady state “snapshot” equivalent, the dynamic modeling is more of a movie than a single picture.

Luyben [12] described the key factors driving the increased popularity of dynamic simulation in the chemical processing industry, such as “increased plant complexity”, “increasing product yield” and “suppressing of environmentally unfriendly by-products”. In the past, dynamic simulation used to be the privileges of large corporations and universities with generous research funding. Typical uses included review of new design and control strategy, modeling transient behaviour, operation and troubleshooting. With technological advances that resulted in declining manufacturing cost and increasing computing power, dynamic simulation tools are now becoming affordable to educational institutions in general. The usage in the universities is primarily for fundamental research at the molecular level, as well as to facilitate understanding of basic chemical engineering fundamentals. Various authors had provided detailed discussions on the use of computer simulations in the context of chemical engineering education [13], [14], [15]. In our context, we are interested in using dynamic simulation as a pedagogic aid to facilitate learning of critical thinking skills.

Suffice to say, in dynamic simulation, natural and chemical phenomena are expressed with algebraic and differential equations based on engineering principles. The mathematical models created are used for analysing how process behaviour varies with time. For the typical case of a process industry, we describe/model the plant subunits and their regulatory control. The relevant equations are solved repeatedly in the time domain and the values of

temperature, pressure, flow and composition as well as the valve openings and the process control system output are calculated at every point of interest. Thus, the interactions between the process subunits can become obvious. We want our students to be able to practice critical thinking using the model explained in the previous section to troubleshoot chemical process plant problems.

METHODOLOGY

We have employed the same integrated CDIO approach currently practiced over the past 3 years of CDIO adoption (Sale and Cheah [16]; Cheah [17]; Cheah and Sale [18]); that is through systematically integrating the development of critical thinking into a suitable core chemical engineering module, instead of teaching it separately in a standalone module. Hatcher [19], in summarizing the research, concluded that an integrated approach to teaching critical thinking give better results than standalone courses.

Also, consistent with our past practices in integrating CDIO skills into our curriculum, we adopted the learning activity design using the student-centered framework “Triangle of Course Design” by Felder and Brent [20] as shown in Figure 2.

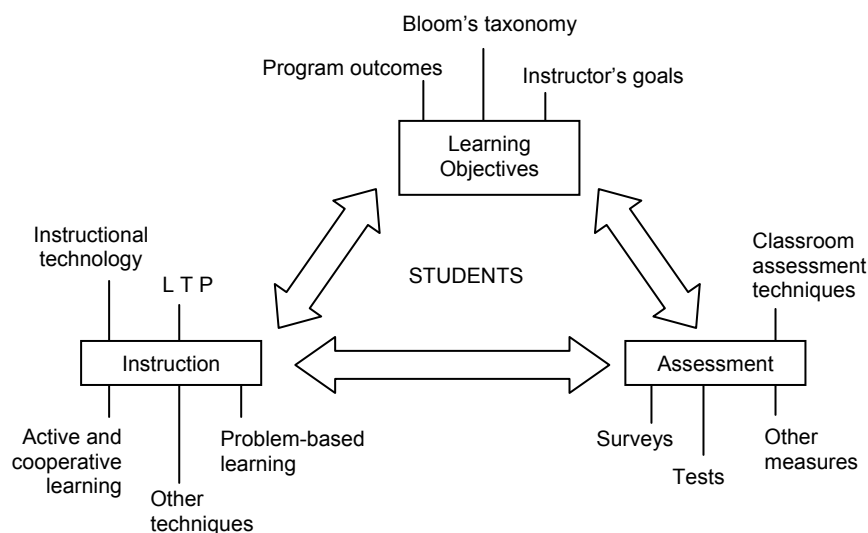


Figure 2: Triangle of Course Design

This seeks to ensure that the learning outcomes are effectively and efficiently developed and assessed through the instructional strategies and assessment systems employed. The advantage of using dynamic simulation has been identified. In the more generic sense, it is aptly summarized by Gurmen et al [21] who noted that:

Interactive computing can greatly facilitate the learning of troubleshooting skills because of the rapid feedback, the alternate pathways the student may progress and the multiple solutions they can generate. Complementary to the traditional classes, interactive computer modules enable the students to create various what-if scenarios and to concentrate on critical thinking.

The research methodology involved a range of qualitative and quantitative methods in order to explore the ways in which students actually went about their thinking when actively involved in solving problems presented in the simulation activities.

The qualitative methods included observation and questioning of students while in the process of problems-solving, as well as focused group interviews of selected students. We also involved several students serving as “co-participants”, a term used by Lincoln [22] (p.78) to describe students who had some personal interest and commitment in taking part in research activities. The student co-participants provide their reflective comments via a designated blog. A typical scenario involves students working in groups on troubleshooting chemical plant processes/systems using dynamic simulation in the presence of the observing researcher. During the simulation activities the researcher would ask students questions relating to their perception of the problems presented and how they were going to respond to them. The students were also interviewed on completion of the simulation exercises. Other data was obtained from a questionnaire survey administered at the end of each semester of study to all students.

The Learning Activity

We used the dynamic simulation package that is available commercially from EnVision Systems Inc (<http://www.envisionsys.com/>), which is used for the training of process technicians and operators. The “model” that we used is the depropanizer unit as shown in Figure 3.

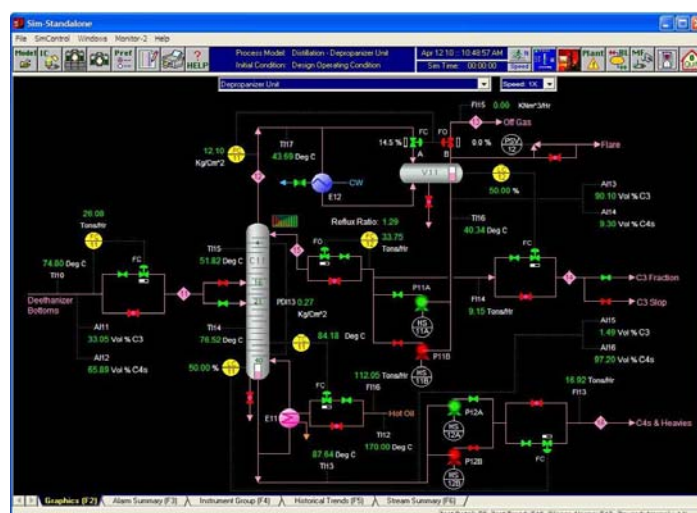


Figure 3. Dynamic simulation model for Depropanizer unit

To promote critical thinking, we have designed a range of activities that involves the skills of analysis, comparison and contrast, evaluation and making inferences and interpretations. For example, in one activity from one of the Year 3 core modules, students have to troubleshoot a process upset in the depropanizer unit, which is a typical real-world task faced by a chemical engineer, as shown in the task scenario shown in Table 2.

For assessment, students were given a range of problem-solving scenarios, for example:

Scenario 1: Explanation of Changes in Plant Operation

From the print-out(s) of the *relevant trends* of the appropriate process parameters, explain how the decrease in reflux rate affects the distillation operation. You need to make explicit connections between the process variables identified. You are restricted to use a maximum of 2 pages of print-outs; so decide carefully what to be printed.

Scenario 2: Submission of Incident Report

Write an incident report (A4 size, 12-point font, single-spacing, not more than 2-pages long) and submit to the chief engineer. Your report should clearly identify the malfunction by drawing conclusion(s) from analysis of the changes in relevant process variables, plant alerts and alarms observed, etc. You should also outline the corrective measures taken to restore the plant to its design operating conditions.

Table 2
Task scenario for activity using dynamic simulation

Task Scenario

Armed with a Diploma in Chemical Engineering from *Kilat Polytechnic*, you recently joined *SuperSafe Chemicals* as an engineering technologist, and were assigned to the Engineering Department. The company's main business is the separation of C3 and other 'light ends' from C4 and other heavier hydrocarbons using distillation.

The company puts you through a series of training programs. Part of the training program is to assess your ability to operate a distillation column. The company uses a dynamic simulation program for this part of the training. The company has arranged for you to attend a training session conducted by the chief engineer, Mr. Tong Bay Khoo. The chief engineer has included two scenarios in this training session:

Scenario 1

You are asked to decrease the reflux flow rate for the Depropanizer unit, observe the change in process parameters, analysing the trends, and explain your observations. You will also be asked to explain some start-up and shutdown procedures.

Scenario 2

The chief engineer has activated an unknown malfunction scenario. You are expected to troubleshoot and identify the unknown malfunction. An incident report should then be submitted to the chief engineer.

The research comprised two interrelated phases. In Phase 1, the initial part of the research, students had not been explicitly taught using a model of thinking as depicted above. The main focus of the research questions were more generally related to the learning experience of students in using dynamic simulation, for example:

- Does dynamic simulation result in a more interesting/motivating learning experience than other methods employed?
- Is the learning more effective and meaningful (e.g., results in better understand)?
- Is thinking evoked in the solving of problems and how is it conceptualized by students?

For this part of the research, from October 2009 until February, 2010, some 40 students were observed and interviewed during the full range of simulation exercises presented.

In Phase 2, from April 2010 to February 2011, we introduced the explicit teaching of good thinking to selected group of students; and carried out further observations and interview. We made comparisons between groups not inducted into the model of thinking with those who have; as well as review the actual performance of students on tasks that require thinking – and any comparisons with those who have not been inducted.

For this part of the research, we divided one class of approximately 20 students into 5 groups, each group with 4 – 5 members. The grouping was formed by the faculty in charge of the module, deliberately mixing up students of different academic capability, so that no

one group had a congregation of top students, which if left to their own free will, will form their own groups. Two of the five groups are then selected as the “Treatment” Groups, where they are explicitly taught the use of the thinking model. The other three groups serve as the “Control” Groups.

Every alternate week, one group of students will carry out the activity in the presence of a faculty, who will take notes of their discussions. During the laboratory session, the treatment groups were specifically encouraged by the faculty to utilize the various types of thinking. Student co-participants are distributed in both “Treatment” and “Control” Groups, and write in their blogs regularly on their experience of CDIO skills introduced into lessons. A focus group discussion is conducted at the end of the semester, comprising both co-participants and other students.

Findings and Analysis

The salient findings from Phase 1 are summarized below:

All students responded positively to use of simulation as a means of providing a more interesting and meaningful learning experience than other methods used in their teaching programme. However, the experience was enhanced or mitigated based on a number of factors. The key factors that enhanced learning related to the nature and variation of problems set. Generally, more challenging and varied problems were preferred, providing they were achievable based on prior learning and within the times frames allowed. More routine problems and time waiting for changes in the simulator state were the main negative aspects of the learning experience for the majority of the students interviewed. In terms of learning students felt that the use of dynamic simulation helped to build understanding of the working and relationship of the various chemical processing systems and their subunits.

The findings clearly supported a view that simulation can be an effective tool for promoting thinking. This was apparent from the student response and observations by the researcher. However, all the students, though with some variation, were unable to offer a descriptive and/or illustrative model (albeit an implicit one) of what good thinking or critical thinking entailed. Typical responses were as follows:

- “Use knowledge to solve problems”
- “Thinking out of the box”
- “Conscious mind, a good amount of reasoning”

These initial findings indicated to us that explicitly teaching of critical thinking skills, using a suitable model as a guiding framework, may well support student learning in terms of the development of good thinking.

Key findings from Phase 2 are summarized below:

Results from the student feedback indicated that overall students are able to use some of the types of thinking. For example, 71.4% students responded (out of 49 respondents) either “Agree” or “Strongly Agree” that they were able to “think critically when solving problems during the practicals, as well as the questions posed during debrief”. However, those explicitly taught the use of the thinking model are able to do so in a more systematic and confident manner, as discerned from the replies given in focus group discussion and blogs. For example, it is noticeable from the blogs that students who were explicitly taught the thinking model are better able to articulate their thinking processes during their group discussions, using “the language of thinking”, such as “compare and contrast”, “infer and interpret”, etc. This is further confirmed by the faculty who observe the conduct of the dynamic simulation exercises.

During subsequent debrief sessions the faculty also noted that these students are able to offer a more coherent explanations of their observations and actions in arriving at the correct conclusions to accurately identify the unknown malfunction. This is also reflected in the Incident Report, where students who were explicitly taught the thinking model are able to produce better quality accounts, in terms of systematically detailing way their approach of restoring the plant back to its normal operating conditions.

In our focus group interview, students who were not taught the thinking model agreed that having a framework on thinking may help them in the learning process. We noted that these students are able to articulate some elements of thinking during debrief but most are unable to explain what metacognition is.

MOVING AHEAD

The research to date has been informative and encouraging. We have established the potential use of dynamic simulation as a useful learning tool, both in terms of encouraging critical thinking and enhancing motivation, when used from a sound pedagogic perspective.

We have introduced the model of thinking into the DCHE curriculum by explicitly teaching it in a core Year-2 module entitled *Plant Safety and Loss Prevention*. We also recognize that merely encouraging students to practice critical thinking in a single module is not sufficient to internalize the full range of cognitive heuristic necessary to facilitate a high level of understanding and competent application. It is essential that other lecturers use the same model of thinking in their modules to reinforce these skills and facilitate transfer. As noted by Marzano [3]:

... we can improve students' ability to perform the various processes by increasing their awareness of the component skills and by increasing their skill proficiency through conscious practice. (p.65)

It is necessary, therefore, to encourage widespread use of the critical thinking model in other core chemical engineering modules. The challenge remains for faculty to design more learning activities that explicitly encourages skill in critical thinking. Hargreaves and Grenfell [23] for example, had asserted that most faculty still held the assumption that "students will learn from the implicit values buried deep within our teaching philosophies." To address this situation, induction workshops have been conducted for faculty by the authors to provide guidance in using the model and how the use of dynamic simulation can facilitate the acquisition of critical thinking skills.

Also, faculty need to be encouraged to be more reflective in their practice in order to be situationally aware of their thinking, making it explicit where necessary for students, and guiding them as they solve problems. It is certainly the case that direct modeling of meta-cognitive thinking by faculty is useful in making explicit to students the mental operations involved and how they contribute to the effectiveness of the overall thinking process. As noted by Mimbs [24]:

Teachers need to model critical thinking skills to their students and explicitly teach them to think critically. Teachers can be transformed in their teaching and students can be transformed in their learning through continued, consistent use and application of critical thinking skills.

This is supported by Mandernach et al [25] who noted that the "key to the success of a discussion in fostering students' higher-order thinking strategies is the instructor's interactivity in leading the discussion. Instructors who actively engage their students via a

more critical exploration of course concepts are more successful in promoting students' critical thinking than those instructors who take a more passive role in their teaching.”

SUMMARY AND CONCLUSIONS

Introducing an explicit model of thinking as part of the instructional approach seems highly promising based on the qualitative data obtained from the various sources documents in the paper. However, it has yet to be verified in more quantitative performance outcomes over time. This will require further and more substantive research in future.

In conclusion it certainly make pedagogic sense to help students to clearly understand what good thinking actually entails (the cognitive heuristics involved), provide them with opportunities for active and experiential application in real world contexts, as well as provide clear and useful feedback on an ongoing basis. The summary frame in this context is well captured by Sheppard et al [26] when they argue that:

... teachers have to make their own intellectual processes (their performances) visible. This means that the teacher-expert has to make visible to learners the otherwise invisible processes of thinking that underlie complex cognitive operations at the heart of engineering thinking. Teachers have to articulate and demonstrate rather than assume the thought processes they want students to learn.

... Then student's efforts to replicate these thought processes need to be made visible so that the teacher can see where the learner is on and off track, in order to provide appropriate coaching and feedback. (p.188)

By designing more learning activities that allows the practice of critical thinking would certainly help to create the much needed opportunities for future research into this very important area of professional concern.

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AN ATTEMPT TO HANDLE THE CALCULUS PROBLEM

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ABSTRACT

For many years now, we have experienced a negative trend concerning the mathematics skill level of our new engineering students. This has been particularly noticeable in the calculus course, which is mandatory for all engineering programs at Jönköping University. To handle this problem, we have made some structural changes to the way we teach the subject, emphasizing the teaching efforts to standard type problems – named ‘A-problems’. A list of categories of such A-problems have been constructed, the purpose of which is to help the student identify the most important ideas and develop the basic skills needed to understand calculus. The students are also given the option to form groups and solve selected problems together and then hand in their solutions for marking. If a group have presented enough correct solutions this grants the group members some bonus points for the final exam, which is divided into two parts where the first one deals entirely with A-problems. During the past few years this way of teaching calculus have been implemented by all math teachers and we are cautiously optimistic concerning the results.

KEYWORDS

Mathematics curriculum, teaching methods, examination

INTRODUCTION

Teaching calculus is a challenge. Maybe it always was like this but these days it can seem like an almost insurmountable task to teach a student how to differentiate a composite function, not to speak of trying to make the student grasp the concept of differentiation in itself. People tend to like challenges though, and this is no exception; teaching calculus, has to be admitted, is also a lot of fun! There are several reasons that makes it particularly challenging today though and we will mention a few here.

Firstly we have to acknowledge the large variability of the skill level our engineering students have in pre university mathematics. This means that some students (unfortunately not many) have quite good technical skills and also understand rather abstract ideas right from start while others may have a hard time adding fractions (I kid you not). The majority of the students are somewhere in between these two extremes of course, but the ‘skill distribution density’ is not symmetric – it has a centre of mass on the lower end of the scale. It also seems that this centre of mass is moving in the wrong direction with time i.e. average Joe knows less today than his older sister did a few years back. This is an unfortunate trend which has been observed in Sweden (as well as in many other western developed countries) for quite many years now. Recently, the results from a large comparative study of the skill

level in mandatory school mathematics of 15 year olds called PISA [1] not only confirms this but also showed that relatively speaking, Sweden is losing ground compared with other similar countries. We had the worst result of the Nordic countries and a mediocre result compared to other European countries. The education system in Sweden is now under heavy scrutiny and a major revision is going to be implemented at pre university level (one idea mentioned in the papers even involved sending out special teams of “elite” teachers to problem schools) and we can only hope that this will change things for the better as swiftly as possible.

Add to the above the fact that mathematics in general, and calculus in particular, is a highly cumulative subject and it stands to reason that we face some non trivial problems when meeting the students in our classrooms.

THE SETUP IN JÖNKÖPING

At Jönköping University all engineering students have to take a basic calculus course which corresponds to 7.5 ECTS-credits, or an eighth part of an academic year in Sweden. The course is taught during a period of 8 weeks and then there is a written exam. Usually there are about 100 students per course and the typical teacher is an experienced lecturer with some background in the research field of mathematical analysis. The teaching methods are comprised of traditional lectures (full class) combined with tutorial sessions in smaller groups.

The curriculum of the calculus course is fairly standard (at least from a Swedish perspective); we start out by introducing the basic properties of the real numbers and we end the course by solving some simple ordinary differential equations. A summary of the topics covered follows below.

- Elementary logic and set theory
- Number systems including complex numbers
- Equations and inequalities
- Elementary functions; definitions and properties
- Limits
- Continuity
- Differentiation
- Integration
- Ordinary differential equations of 1st and 2nd order

Since this is the only calculus course many of our engineering students will ever take, we have made the choice to include everything which is necessary to understand the concept of a differential equation, but very little on top of this. For example, we do not have the time to cover numerical methods more than superficially or to even mention Taylor series which is unfortunate. Some of our students study these topics later in a multi variable calculus course though.

The book used [2] is published only a few years ago but the material is presented in an old fashioned rather rigorous style, there are many similar Swedish books on the market and most university calculus courses uses a book of this type. In our experience, many of the students have a hard time *reading* mathematics by themselves; instead they tend to skip the theory pages (proofs are omitted by default) and jump directly to the exercises, where they then get stuck and call for the teacher to explain things. We believe this to be a behaviour induced from the earlier school systems where mathematics is taught in a very non-theoretical fashion based on repeating exercises at best; the concepts of a theorem and a proof are carefully avoided. The skill of actually *reading* mathematics, following a chain of

written down arguments leading to some conclusion is not developed at all. Therefore there tend to be something of a cultural shock for many students when meeting mathematics at university level where the (good) text books usually are loaded with rigorous definitions, theorems and proofs.

In search of the holy grail

As should be clear from the introduction, mathematics teachers in many countries working at university level have had reasons to seek ways to improve the student results for quite a few years now. Unfortunately, but not surprisingly, no quick fix has been found although a number of different types of educational reforms have been tried, especially in the primary school systems. For example, in the U.S. there has been a rather infected debate going on for a few decades, known as the math wars, about the pre university mathematics education involving (the majority of) researchers of mathematics on the “traditionalist” side and (the majority of) researchers of mathematics education on the other “reform” side [3]. In a nutshell, the reform side want to focus less on computational skills and more on conceptual understanding and exploration, the traditionalists being not so impressed by these ideas. It’s interesting that in Sweden we also have had a similar version of this “war”, with similar groups of people involved on both sides debating similar ideas of reform. Initially the reform side got a lot of attention and many schools tried the suggested new ways of teaching, but now it seems the pendulum is starting to swing back again; the results from the experiments have not been encouraging and going back to the recent PISA study [1], we can see that many of the countries with the best results are also the countries with the most traditional ways of teaching, emphasizing algorithms, algebra and drill type exercises.

The thoughts leading to our reformed calculus course

In Jönköping, going back to how the situation was before the year of 2000, a typical calculus course would get great student reviews which was always a boost for the teacher involved, but at the same time it was a depressing affair to mark the final exam, since a normal result would mean failing roughly 50% of the students. The written exam was constructed in a very traditional way; 8-10 problems was more or less randomly constructed with the aim of testing as many of the learning outcomes as possible. The problems was worth a total of 25 points and in order to pass the course, a student would need to score at least 10 points, and for the higher grades the limits were set to 15 and 20 points respectively.

We knew from experience that at Jönköping university, a typical student that follows one of our 3-year engineering educations at bachelor level does not see mathematics as a very interesting subject in itself, it is only a necessary means for becoming an engineer. Very often the student have very little positive experience of mathematics from earlier school systems, it can be quite the opposite. We mathematicians try to motivate the students as best we know how but it’s not so easy. Recently we have tried to invite a professor of mechanics as a guest lecturer to speak of the necessity of mathematics showing some nice examples. This has been appreciated by the students and we will continue to investigate further ideas as far as motivation go.

Optional bonus point program

So if the students have

- poor initial mathematical skills
- the attitude that almost everything in life is more interesting than mathematics

what should be done? Furthermore, we also had access to statistics indicating that a student is only willing to spend an average of 30 hours per week on school studies, and we realized that there should be a potential for improvement here – we wanted the students to spend more time per week doing mathematics. Trying to accomplish this we chose the way of the carrot rather than the stick and a few years back we therefore invented an optional bonus point program that the students may enrol in. Basically, they have to form study groups of 4 people and hand in solutions to weekly assignments consisting of a number of problems dealing with theory recently discussed in the classroom. We wanted to encourage cooperation and catalyze mathematical discussions so we only demanded one solution per study group. We mark their solutions and hand it back to them with feedback. If they get approximately 80% correct solutions then they will get a number of bonus points for the final exam. The maximum number of bonus points granted is 3 and only valid for scores below 10 (i.e. for the lowest grades). For the higher grades the maximum number of bonus points granted is 2 and 1 respectively.

After implementing this we noticed that the activity during the tutorial sessions increased and we also noticed study groups spending time with these hand in problems during hours not formally scheduled. In some case we even got complains from other teachers that the students were spending too much time doing mathematics, it “stole” time from their course! Not all effects were positive though, we noticed that some students tend to focus almost all their attention to the hand in problems, not doing the regular exercises from the course book. Also, since this is a group task, we can never be sure that all students participate in an equal fashion. Never the less, the bonus point program is still in place today and we see no way back now, we believe the advantages outweighs the few negative effects. One of our teachers have also developed a quite sophisticated system with scripts that automatically generate an arbitrary number of variations of a selected problem so even if there are 100 students, every single one gets individual hand in problems.

THE A-PROBLEMS

The above described bonus point program was implemented in Jönköping after the millennia shift, and afterwards we noticed that the student activity had increased somewhat and the results were slightly improved but not dramatically; we still regularly had final exams where almost 50% would fail. In a way this was now even more depressing because this meant that every other student had scored less than 7 points (out of 25) on the final exam. It should be mentioned that due to rationalization demands during these years the classes that took calculus increased in size; in ten years we went from a typical class size of 50 students to the situation today where you usually have between 100 and 150 students. Obviously this have had some negative effects on the results; at the very least we experience that today we have a larger proportion of students with very weak skills in pre university mathematics compared to the situation 10 years ago.

So, once again we realized that we had to do something. As a teacher group we agreed that a written mandatory final exam is a must in this type of course and we didn't want to change the examination method to a system where almost everything is based on hand in projects or something similar although this could lead to a quick increase in the number of passed students. Such systems are in place at several universities in Sweden but we consider them unfair and arbitrary and we are too much of traditionalists to even consider this as a viable examination system at our department.

We wanted an examination system which guaranteed that if we pass a student then this person would have the skills to independently solve a majority of the problem types we study in the course, let it be on a basic level. In other words, we wanted to honestly be able to claim that at least a majority of the learning outcomes were indeed fulfilled by this same

student. What we came up with was the idea to construct a list of problem types which we now call the A-problems. Essentially, this is an interpretation of the learning outcomes from the course syllabus into concrete problems, or at least concrete problem types, more well defined than the somewhat general descriptions of the learning outcomes. Our hope and intent was that this list would be particularly helpful for the typical weak student when trying to grasp what kind of skills he or she is expected to learn from the calculus course. For a problem type to appear on this list we required that

1. the problem type should be a concrete example of a skill described as a learning outcome in the course syllabus
2. the mathematics involved in the problem type should be “new” to the student, i.e. the problem type should not have been covered in earlier math courses from pre university education.

The syntax used for each problem type when writing the list was to start with a description of the problem type, followed by one or more concrete examples of this problem type. For each problem type we also make references to the relevant exercises in the course book that deals with this particular problem type. This means that the list both defines what is considered an important skill and it also helps the student to develop this skill. Finally, we give the students two versions of the list; one exactly as described above, and another version where we have provided detailed solutions to our example problems.

A new final

The point of the A-problem categorization is made clear only when seen in the context of the final written exam. We wanted to be able to tell the students “If you learn how to solve all these different problem types which appears on the A-list then you will have no trouble passing the final exam”. In order to make the truth of this statement perfectly clear to the students we decided to change the form of the exam dividing it into two parts. The first part, called part A, deals *only* with A-problems and here it is possible to score a maximum of 15 points i.e. more than enough to pass the course (recall that the grade limits are 10/15/20 points respectively).

The second part of the exam, called part B, consists of more demanding problems worth a total of 10 points. Our ambition is to construct these B-problems in a way so that when solving these problems the student either has to combine several different skills learned from solving A-problems, or has to come up with some new ideas i.e. it is not enough to be able to repeat a standard algorithm, some creative reasoning is also necessary. This means that even the quite talented student can get some kicks out of this course, and it also has the upside that for the teacher this B-part is quite fun to construct (although it takes a lot of time; I can spend several days constructing one final exam). We also have the rule that we will only mark the part B if the student has scored at least 10 points on the part A, this in order to make sure that a passed student has learned enough basic skills which correspond to the learning outcomes of the course.

It should be mentioned that we do not allow our students to use calculators when writing the final exam. We have the experience that many students have developed a behaviour where they rely much too heavily on calculators in their earlier mathematics education, being able to solve some types of problems without having a clue what they really are doing mathematically speaking; essentially they just press some buttons and take whatever result the calculators produce as an undisputed “truth”. The pros and cons of using calculators is a huge topic that deserves a paper on its own so I will simply make this statement leave it at that for now.

EXAMPLES

The learning outcomes

Here I will list the learning outcomes from the course syllabus and hopefully it will later on be clear how these have been interpreted as A-problems.

After completion of the course the student should be able to

- perform simple calculations involving complex numbers.
- understand the concept of a function and especially know how the elementary functions behave (elementary functions means polynomials, trigonometric functions and their inverses and exponential and logarithm functions).
- solve basic equations and inequalities involving the elementary functions.
- understand the concept of a limit and be able to compute simple limits by using standard limits
- understand the concept of continuity and use the fundamental theorems valid for continuous functions
- formulate the definition of a derivative and understand its interpretation in various situations
- differentiate expressions involving the elementary functions by using the differentiation rules and to use the derivative as a tool when sketching graphs and for solving applied problems such as optimization problems
- compute simple primitive functions, definite integrals and generalized integrals
- solve linear and separable first order differential equations of and second order linear differential equations of second order with constant coefficients.

A selection of A-problems

I will now give a couple of examples of A-problems generated from the learning outcomes. Some A-problems we have derived directly from one single learning outcome while others take in aspects from several learning outcomes. After each problem type description I will also give concrete example problems of the corresponding type.

A-problem: Performing basic calculations involving complex numbers represented either in Cartesian or polar form. Solving equations of the form $z^n = w$ where n is a positive integer and w is a complex number.

- Let $z = \frac{3+4i}{1-i}$. Write z in the form $a + bi$ and compute $|z|$.
- Solve the equation $z(3 + i) - 2i\bar{z} = 2$.
- The equation $z^4 - 3z^3 + 2z^2 + 2z - 4 = 0$ has one solution $z = 1 + i$. Find the other three solutions.
- Find all solutions to the equation $z^3 = 8i$. The answer should be in Cartesian form.

A-problem: Solving equations involving square roots.

- Solve the equation $\sqrt{2-x} = 2x - 1$.

A-problem: Solving equations and inequalities involving rational functions and the absolute value function by using a sign table or division into separate cases.

- Solve the inequality $\frac{x^2-10}{x-3} \leq 3$.
- Solve the inequality $|x - 5| + |x + 3| < 10$.

A-problem: Calculations involving elementary functions including computations of domains, ranges, inverse functions, derivatives.

- Let $f(x) = e^{2x}$ and $g(x) = \sqrt{x}$. Determine the functions $f(g(x)), g(f(x))$ and describe their domains and ranges.
- Determine whether or not the function $f(x) = \ln(x - x^2)$ is invertible.
- Compute the tangent line at $x = 2$ to the function $f(x) = \arctan\left(\frac{2}{x}\right)$.

A-problem: Solving equations involving logarithms and exponential functions.

- Solve the equation $\ln(4x + 22) - 2\ln(x + 1) = 1$.

A-problem: Solving equations involving trigonometric and inverse trigonometric functions.

- Solve the equation $\arcsin(x) - \arccos(x) = \frac{\pi}{6}$.

A-problem: Computing derivatives using the definition of derivative.

- Use the definition of derivative to compute the derivative of $f(x) = \frac{1}{\sqrt{x}}$.

A-problem: Using the derivative as a tool for solving optimization problems and sketching the graph of a function.

- Sketch the graph of the function $f(x) = \frac{x^3}{x^2 - 1}$. Also find all local extreme values of this function and compute any asymptote that might exist.
- Find all extreme values of the function $f(x) = |x + 1|e^{-x/2}$ if the domain is set to be the interval $[-1, 2]$.

A-problem: Finding primitive functions using the method of substitution.

- Compute $\int \sin(x)\sqrt{2\cos(x) + 1} dx$.

A-problem: Finding primitive functions using the method of integration by parts

- Compute $\int (x + 1)\ln(x) dx$.

A-problem: Solving linear and separable first order differential equations.

- Solve the differential equation $xy' + \frac{1}{2}y = x^2, x \geq 1, y(1) = 1$.
- Solve the differential equation $y' = y^2 \cos(x)$.

A-problem: Solving second order linear differential equations with constant coefficients of the form $y'' + ay' + by = f(x)$. The function $f(x)$ is either a polynomial, a trigonometric function or of the form $p(x)e^{kx}$ where $p(x)$ is a polynomial.

- Find all solutions to the differential equation $y'' - 2y' - 3y = 2e^{3x}$.

Some of the B-problems

Since a B-problem can be pretty much anything, I just give a couple of examples of what has been given as exam problems so the reader get the flavor.

- Let $f(x) = \frac{1}{2}e^{2x} - 3e^x + 2x + 1$. Find the smallest number a such that $f(x)$ is invertible on the interval $[a, \infty]$. For this a , find the domain of the inverse function.
- If $f(x)$ is a continuous function such that $0 \leq f(x) \leq 1$, show that the equation $f(x) = x$ must have at least one solution on the interval $[0,1]$.
- Which is largest of the numbers $1, \sqrt{2}, \sqrt[3]{3}, \sqrt[4]{4}, \dots$
- Find the range of the function $f(x) = e^x \ln(1 + e^{-x})$.
- Find positive numbers x_1, \dots, x_{10} such that the expression $\frac{x_1}{x_{10}} + \frac{x_2}{x_9} + \dots + \frac{x_{10}}{x_1}$ becomes as small as possible.
- The heating system suddenly stops in a house where the temperature initially is 20°C . Assume the temperature gradient to be directly proportional to the difference between inner and outer temperature. If the temperature in the house after 2 hours is 15°C , what is the temperature in the house after 24 hours?

CONCLUSIONS – THE GOOD, THE BAD AND THE UGLY

The good,

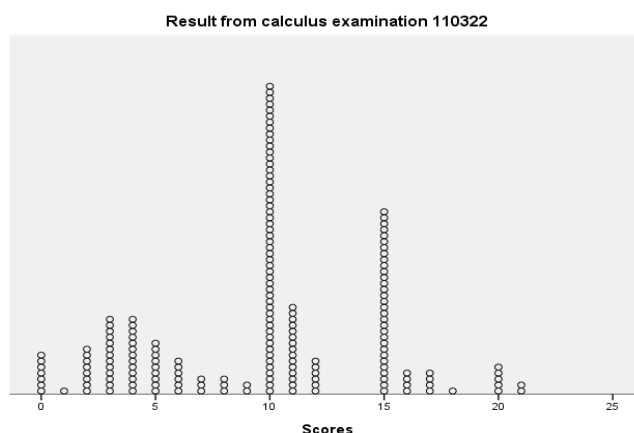
After this system has been in place now for a couple of years we have noticed a slight increase as far as the results from the final exam go. The increase is not very large though; in general some two thirds now pass the first final exam which is only slightly better than before. We have got mainly positive feedback from our students and they really seem to like this system where the question “what should I study in order to pass the exam” seems to have been answered once and for all.

the bad,

On the negative side we see that many of the students now focus entirely on the A-problems in order just to pass the exam (with the lowest grade) even though they many times have the potential to get higher grades. We also suspect that some students fail that today that would have passed with the old type of exam where they could try to solve more types of problems than today.

...and the ugly

It could be argued that although the results now are somewhat better when looking at the final exam, we are not so sure if the students that pass the calculus course today really *are* better than they used to be. Many of the students that pass the course today seem to have quite shallow understanding of sometimes very fundamental concepts in Calculus although they know how to solve a sufficient number of A-problems. Maybe in the future it would be good to try to incorporate more problems that tests conceptual understanding rather than the ability to learn and repeat algorithms. As always, the results we arrive at in the end of the course very much depend on *how* we try to measure the skill level of our students. I will include a typical but quite ugly picture of my latest final exam. Here 185 students took this exam and around 160 of these have followed the course seriously, participating in the bonus point program.



As can be seen some 120 students score 10 points or more which means that they pass. The reasons for the abnormal heights at 10, 15 and 20 points is explained by the fact that the bonus points kick the score to 10, 15 or 20 if the actual score was in the range 7-9 points, 13-14 points or 19 points respectively. Apparently, quite a few of the students (that scored in the interval 7-9) have not managed to solve more than 3 of the A-problems correctly and therefore had to rely on the bonus points in order to pass the course which is a bit sad in the end.

The question still remains: how do we teach calculus to a large group of students in a very limited time with very limited resources? The answer is that we have no clue but we keep trying anyway.

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This paper is merely a subjective documentation of a joint collaboration between the mathematics teachers working at the School of Engineering, including Anders Andersson, Kenneth Hulth and Tjavidar Ivanov. These people deserve credits not only for coming up with the ideas which I have tried to describe in this paper but also for making it fun to go to work every day.

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INTRODUCING CHIP DESIGN USING SPEED OF LIGHT

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ABSTRACT

We present a novel didactical concept for undergraduate teaching of microelectronics based on an experiment using a CMOS cyclic pulse-shrinking time-to-digital-converter (TDC) in order to directly measure the speed of light. With emphasis on the design of a TDC for didactical purposes we use this concept in the core courses for chip design on transistor level. It starts with demonstration experiments in the physics course and in the electronic devices course in order to boost enthusiasm for microelectronics. In the context of our research on road safety we demonstrate the relevance of the field. A SPICE course and an introductory course on chip design at transistor level follow, including project-based learning, i.e. design, simulation and layout of TDC components. Within a laboratory project on electronic devices after fabrication of a chip the students are offered to characterize their own designs or to develop a microcontroller circuitry to use it. We present the integration of our concept into the syllabus of microelectronics education at the University of Applied Sciences Aschaffenburg, its operational learning objectives and the achieved learning outcomes including active learning and CDIO design-build experience. Evaluation of the courses shows that the acceptance of the didactical concept is above 90%. The speed of light experiment is ranked first by our students.

KEYWORDS

Project-based learning, chip design, TDC, speed of light, Ko-FAS

INTRODUCTION

The finite speed of light plays a fundamental role in physics and has important applications in many areas of engineering. This is observed in everyday life, e.g. using the Global Positioning System (GPS), Radio Detection and Ranging (RADAR) and laser distance meters. Nevertheless, more than 80% of our students in the first days of their academic studies do not expect that speed of light, which they know very well, can be measured on a tabletop. They never have seen any measurement before. We present this experiment in the basic physics courses of engineering education and we observe that it is denoted as a fascinating key experiment by our students. With respect to microelectronics education we have developed a novel concept in order to introduce chip design using this experiment. This concept fits into the CDIO design-implement experience and is outlined below.

The measurement of speed of light is well established in the laboratories of higher education. As modern oscilloscopes provide time resolution in the order of picoseconds, direct methods have been introduced that measure the delay of a laser pulse while travelling a short distance, e.g. [1]. By means of these experiments the student, however, up to now does not learn how the necessary time resolution is obtained electronically. For microelectronics education we instead use the inherent fascination of this experiment to introduce a simple CMOS circuitry, the cyclic pulse-shrinking TDC, in order to clarify exactly that and we explain the respective chip design. In contrast to previous experiments described in literature, where speed of light is measured, we do not place emphasis on the accuracy of measurement but on the design of the TDC.

It is widely expected that a long distance is necessary to measure the delay of a laser pulse while travelling. In a first step we use that expectation in order to raise *Attention* to the field of microelectronics by demonstrating an unexpected experiment. We show in the basic physics courses that few centimetres are sufficient using a commercial TDC and we point out that students may develop such a circuitry by presenting one of our respective dies under the microscope. At the same time we motivate our students to try the marshmallow-method [2] at home.

In the second step during the course on electronic devices we repeat the experiment with our own TDC. In the context of our research on intelligent sensors and on road safety we demonstrate the relevance and importance of the subject and we discuss the aims of our industrial research partners. By presenting a current research application of a laser distance measurement we raise *Interest* on the subject. At that stage the students are familiar with the basics of RC-circuitry and MOSFET operation. This puts us in a position to explain at an undergraduate level, how the cyclic pulse shrinking TDC works, to illustrate that by simulating the propagation delay of gates with SPICE, and to introduce, how chip layout is done. If the students feel that they got how it works, we succeed in raising the *Desire* to do it by themselves. Our *Action* then is to offer a SPICE course and an introductory course on chip design at transistor level, including project-based learning, i.e. design, simulation and layout of TDC components. After fabricating a chip the students are offered the chance to characterize their own designs or to develop a microcontroller circuitry that uses the TDC in a laboratory project. The individual projects are designed to meet industry requirements.

The remainder of this paper is organized accordingly. First of all we present the syllabus and the learning objectives with respect to speed of light and time-to-digital conversion. We propose respective topics to be covered in a SPICE course, in an introductory course on chip design and via project-based learning. In a second step we describe our experimental setup for the measurement of speed of light, our didactical concept of undergraduate teaching the TDC operating principle, an example realization of a TDC for didactical purposes, respective results of measurements and a current research application of LIDAR. We present an evaluation of the concept including learning outcomes, before we summarize the main conclusions.

SYLLABUS AND LEARNING OBJECTIVES

Figure 1 shows the course flow and the higher-level objectives of our concept. Table 1 summarizes the operational learning objectives of the courses with respect to speed of light and TDCs and Table 2 presents the integration into the syllabus. Note, that at any stage of the course flow these special learning objectives fit well in the overall learning objectives of microelectronics education.

The basic tabletop experiment demonstrated in the Physics course is performed interactively, i.e. the students learn to document an experiment, evaluate the speed of light from the data

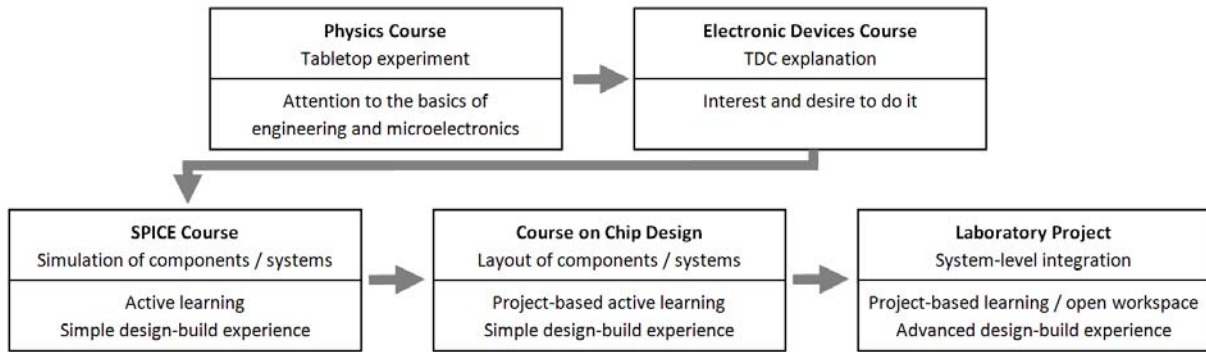


Figure 1. Course flow and higher-level objectives of our concept

Table 1
Operational Learning Objectives with Respect to Speed of Light and TDCs

Physics / Tabletop experiment	
<ul style="list-style-type: none"> - Explain the principle of a time-of-flight measurement - Estimate time / distance requirements for laser distance measurements by mental arithmetic - Estimate the error of measurement with respect to the definition of the speed of light 	<ul style="list-style-type: none"> - Explain the difference between resolution, sensitivity, accuracy and evaluate these - Explain common methods for measurement of time - Explain what a TDC does - Design a time-of-flight measurement
Electronic Devices / TDC explanation	
<ul style="list-style-type: none"> - Show the circuit diagrams of an inverter and of a NOR gate - Calculate the switching point of an inverter using SPICE level 1 equations - Explain the sources of propagation delay of an inverter 	<ul style="list-style-type: none"> - Calculate the propagation delay of the rising and falling edge of an inverter - Show, explain and design the circuit diagram of a pulse-shrinking TDC
SPICE / Simulation of components	
<ul style="list-style-type: none"> - Simulate switching points and propagation delays of CMOS inverter and NOR gates - Design an inverter with predefined propagation delays of the rising and falling edge, verify by simulation 	<ul style="list-style-type: none"> - Design a pulse shrinking TDC and verify its correct operation by simulation - Organize in groups, partition the work and fit all together
Chip design / Layout of components	
<ul style="list-style-type: none"> - Layout a CMOS pulse shrinking delay line - Apply common centroid layout to minimize delay jitter 	<ul style="list-style-type: none"> - Organize in groups, partition the work and fit all together
Lab. Project / System-level integration	
<ul style="list-style-type: none"> - Design a complete TDC-chip according to predefined specifications - Organize in groups, partition the work and fit all together 	<ul style="list-style-type: none"> - Design, realize and evaluate a microcontroller circuitry for a TDC-based sensor, using a previously fabricated TDC

measured, estimate the error of measurement, discuss sources of parasitic delay and propose improvements which are realized during the lecture, if possible. By discussing engineering applications and exhibiting integrated circuits developed within our course of chip design we raise attention to the basics of engineering and microelectronics.

Table 2
Integration of our Concept into the Syllabus of Microelectronics Education

Course	Semester	Workload in total lectures	Workload of our concept in lectures
Physics 1	1	28	2
Electronic Devices	3	28	4
SPICE	4	14	1
Chip design	4	14	6
Lab. Project	6	14	14

The second experiment in the Electronic Devices course is used to introduce demonstratively simple digital CMOS circuitry, the respective propagation delay and an industrial example of use. The principle of operation of the cyclic pulse-shrinking TDC is explained on the basis of SPICE level 1 equations. By outlining how it is designed, we raise interest and desire of our students to do it.

Within the interactive SPICE course we teach simulation of microelectronic components and systems with integrated supervised exercises. These include simulation of the transfer functions of CMOS inverter- and NOR-gates, the step response of the inverter, Monte-Carlo- and worst-case-analysis of propagation delays and the application of an optimizer to determine gate width for a given propagation delay goal and predefined gate length. With respect to the TDC, the students learn to design the switching point and the propagation delay of rising and falling edges using the transient analysis of SPICE. Afterwards they are able to organize themselves in groups in order to design a simple pulse shrinking element and verify its operation with respect to an appropriate design goal. This is a first step towards active learning and CDIO design-build experience.

We use an analogue approach in the directly following course on Chip Design at transistor level. Besides elementary analog design, full custom design of basic gates for a 0.35 μm CMOS process is taught. After learning common layout skills the students handle a small personal layout project with predefined design goals. Students who like to work in a group may choose any of the matched components of a TDC as a personal task and finally build a complete TDC. They have to organize themselves in groups and to partition the work in order to achieve the design goal in appropriate time. We effectively stimulate this work by promising that all designs that pass the DRC and that meet the design goals, verified by post-layout corner simulation, will be fabricated as a multiproject chip via the EURO PRACTICE foundry service [3]. Typical project examples are a cyclic pulse shrinking delay line or a differential amplifier. This is a first step towards project-based active learning and a second step towards CDIO design-build experience.

After fabricating a chip the students are offered the chance to characterize their own designs, to implement a complete TDC or to develop a microcontroller circuitry that uses the TDC in a laboratory project. The individual projects are designed to meet industry requirements. For example, different concepts of TDC-based temperature sensors and pressure sensors have been realized and analysed in cooperation with local industry. For these projects the students are organized in groups which may either cooperate or act as competitors, just as they want to do. Each person, however, must demonstrate individual effort and creativity.

The groups are offered an open workspace, comprising the laboratories for Physics, Electronic Devices, Computer-Aided Circuit Design and Computational Intelligence, whole over the week. Finally, by a consecutive bachelor or master thesis, interested students may complete their specific knowledge and present novel ideas at a conference [4].

MEASUREMENT OF THE SPEED OF LIGHT USING A CMOS CYCLIC PULSE-SHRINKING TDC

We use the common operating principle of laser distance meters. A light pulse emitted from a laser diode is reflected by an object at distance D (two mirrors in our case) back to a photodiode at the same distance. The time of flight Δt is correlated to D according to:

$$2D = c \cdot \Delta t \quad (1)$$

where c denotes the speed of light in the medium used. If D and Δt are measured, one may confirm the value of c . As the value of c in vacuum is fixed by the definition of the metre, measurement of Δt can be used to measure D . We emphasize the measurement of Δt with appropriate resolution using a CMOS circuitry.

Experimental Setup

Figure 2 illustrates the information flow our experimental setup. Figure 3 shows the optical path. As our target audience are students of electrical engineering who learn to handle all the instruments used, there is no need to keep the apparatus simple or inexpensive. We use a high precision pulse generator in order to produce an electrical trigger-pulse of well defined duration and selectable duty cycle, typically 1 ns and 1 ms, respectively. This pulse is converted into a light pulse by a laser diode circuitry which we disassembled from a commercial laser distance meter. The light pulse is fed back via a slidable reflector (two mirrors) into a pin diode connected to a current-feedback amplifier (THS3201) in order to generate an electrical response pulse. The delay between the rising edges of the trigger pulse and the response pulse is visualized by an oscilloscope and converted into a single pulse duration via a flipflop. Our cyclic pulse shrinking TDC internally produces a number of output-pulses proportional to the duration of that single input-pulse. These pulses are counted and thus provide the digital output. For repeated measurements, the simultaneous reset pulse of the TDC and of the counter is synchronized with the laser diode pulses. Note with respect to low budgets, that high precision apparatus is not necessary for this experiment. For alternative solutions and details of FPGA-controlled pulse generation, laser diode circuitry, laser safety precautions and photodiode circuitry we refer to the literature [1], [5].

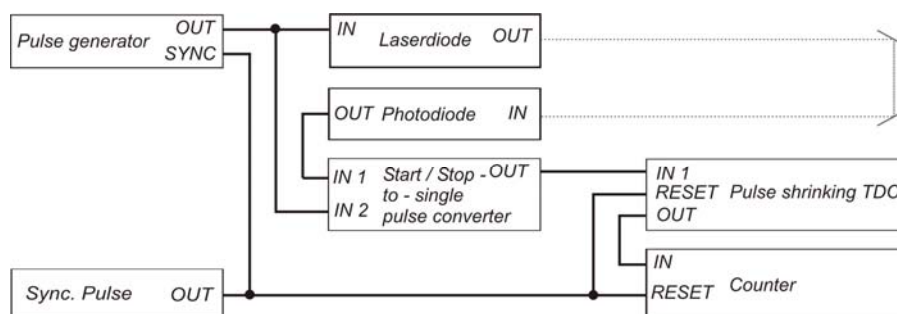


Figure 2. Block diagram of the information flow

Figure 3 shows the laser at the center, a slidable reflector at the right and the photodiode and TDC at the left. Starting the experiment at an arbitrary position of the reflector close to the

laser diode results in a delay offset which is due to the time of flight but also to the contributions of the diodes and their circuitry and of the signal transmission lines to the delay. This partly is a desired effect, as our TDC requires a minimum pulse duration of about 15 ns for operation. We adjust the reflector to start with a delay of 20 ns and perform differential measurements by increasing the distance between reflector and laser diode.

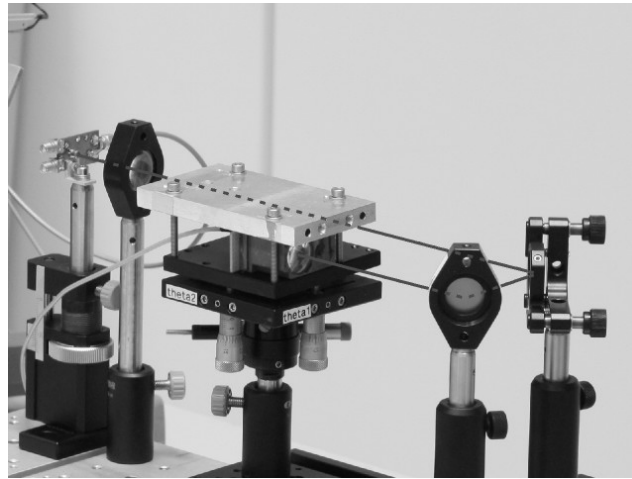


Figure 3. Optical path of the laser distance measurement on a tabletop using our TDC

The smaller the contribution of the time of flight to the offset, the more important becomes the error due to the remaining contributions induced by the displacement of the reflector. Careful alignment of the optical path is essential to ensure that the rise time of the response-impulse does not change more than some hundred picoseconds. We realized a rise time of about 2 ns and a scatter of about 200 ps within a displacement of 1.5 m.

The Pulse Shrinking TDC Operating Principle

Early realizations of a CMOS pulse shrinking TDC have been presented in [6], [7]. Its basic operation is to shrink the duration of an input pulse. To see, how that can be done, assume that we have any digital delay element that switches at 50 % of the input signal. Assume further that we can construct a propagation delay time $t_{p_{LH}}$ for the Low-to-High transition that is greater than the propagation delay of the High-to-Low transition $t_{p_{HL}}$. If we feed a pulse into this delay element we get an asymmetric delayed pulse at the output as indicated in the upper half of Figure 4. If we feed this asymmetric pulse into a symmetric delay element, its output pulse is shorter than the original pulse.

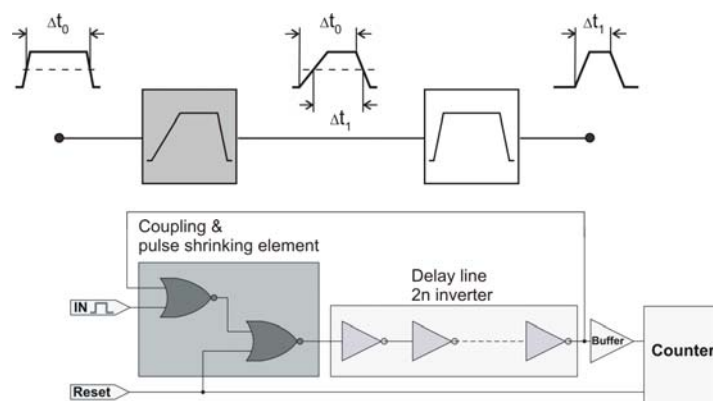


Figure 4. Pulse shrinking principle (upper half) and block diagram of the TDC

Note, that the final output pulse would be stretched, if we would construct the asymmetric delayed pulse such that $tp_{LH} < tp_{HL}$. If we connect further symmetric delay elements in series to form a delay line, the total propagation delay will increase without change of the pulse shrink. Finally, according to Figure 4 we use two NOR-gates to generate the asymmetric propagation delay, to allow reset of the delay line and to implement a feedback loop from the output of the delay line to the input of the NOR-gates. As a result the input pulse is shrunk by the same amount after each pass through the delay line until it vanishes completely. The delay line ensures that its output pulse is fed back only after the falling edge of the input pulse. Additionally, further pulses to be measured must not arrive at the input during cycling a pulse. In order to perform time-to-digital conversion, the output pulses of the delay line can just be counted using a buffer and a ripple counter. For our demonstration experiments, we show these pulses with an oscilloscope and we use an external counter.

Realization of a TDC for Education

Though any digital delay element can be used in order to build the delay line we start our educational program with the basic inverter as it is part of the ordinary courses on electronic devices, simulation with SPICE and the introductory course on chip design at transistor level. Figure 5 shows the schematics of our basic delay cell and a switch-based simple equivalent circuitry for explanation of the operating principle. For didactical reasons we have omitted temperature compensation [8] and stabilization of the supply voltage V_{DD} . As a result we are in a position to demonstrate the respective effects and our basic delay cell is kept rather simple while it operates sufficient for an appropriate measurement of speed of light.

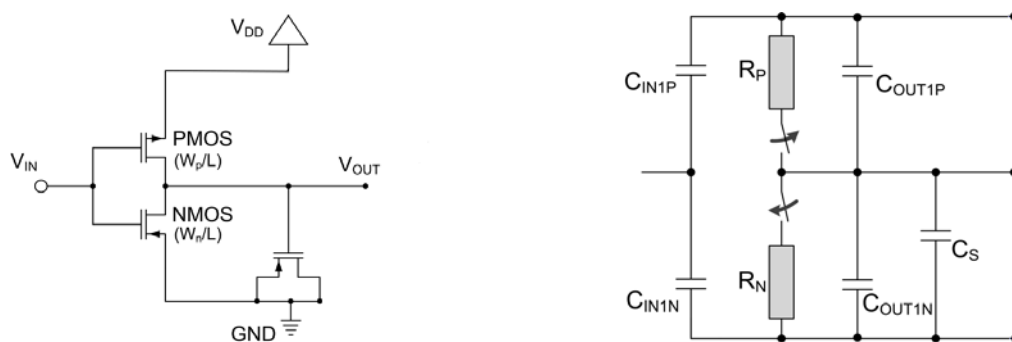


Figure 5. Schematics of our basic delay cell and a switch-based simple equivalent circuitry

At the beginning of the course on electronic devices the students are familiar with the step response of an RC circuit, so tp_{LH} and tp_{HL} are explained by a first order RC delay model, as shown at the right hand side of Figure 5. The NMOS capacitor C_S connected in parallel to the gate capacity of the following inverter is used for two reasons: at first, in order to operate the device at a frequency that allows easy access to all signals outside the chip and secondly to introduce the nonlinear $C(V)$ -behaviour of this device. The equations which describe the propagation delay for a switching point at 50% of the amplitude

$$tp_{HL} = 0.7 \cdot RN \cdot C_{load} \quad (2)$$

$$tp_{LH} = 0.7 \cdot RP \cdot C_{load} \quad (3)$$

illustrate that an asymmetric delay element can be obtained by designing different load currents i.e. appropriate W/L ratios for the NMOS and PMOS. Generally, for two successive gates the pulse width P is reduced by ΔP

$$\Delta P = -(tp_{LH1} - tp_{HL1}) + (tp_{LH2} - tp_{HL2}) \quad (4)$$

if $\Delta P < 0$, [9]. In order to get useful equations for a hand-calculation-based design, the basic differential equation describing the charging/discharging process has to be integrated because the drain-source-voltage surpasses the saturation voltage during charging/discharging. Though the equations are easy to derive, [4], [7], this is out of the scope of our electronic devices course and usually part of a student research project. For the TDC design, however, the students have to become familiar with this approximate description and thus with the influence of mobility μ , threshold voltage V_T , supply voltage V_{DD} , capacitive load C_{load} , and gate width-to-length ratio W/L .

On our test chip we use 108 inverters within the delay line with an overall propagation delay of 290 ns (2.7 ns per inverter). As the pulse shrinking is due to propagation delay differences (see Equation 4) the cyclic pulse shrinking TDC operates with sub-propagation-delay time resolution which in first order is independent of technology parameters. We have fabricated test chips in 0.35 μm CMOS-technology [4] and we obtain a minimum pulse shrink of 120 ps. The minimum input pulse length is 15 ns. For an input pulse of 290 ns it needs about 0.8 ms until the pulse has vanished completely, the duty cycle of the input pulses must be adjusted accordingly.

Experimental Results

Figure 6 shows results which we obtain with our demonstration of laser distance measurement. The TDC has been calibrated between 27 ns and 37 ns using a high precision pulse generator (right side of Figure 6). The scatter of the time data is within 1 ns to 1.5 ns. The left side of the figure shows measured pulse counts and its reproducibility corresponding to times of flight for reflector displacements in steps of 10 cm. Every measurement has been repeated 100 times. Note, that evaluating the mean from count statistics may result in sub-count resolution which is limited, however, by the stability of the signal. Evaluating the time data at the limits, i.e. measurements 1-100 and measurements 1001-1100 corresponding to a displacement of 100 cm results in a speed of light of $2.90 \cdot 10^{10}$ cm/s, linear regression results in $2.92 \cdot 10^{10}$ cm/s. The resolution of time measurement obtained in these experiments is 260 ps, the corresponding resolution of distance measurement is about 4 cm. By an appropriate design of the TDC chip or by using a state-of-the art commercial TDC the time resolution may be reduced to about 10 ps. Due to the limited stability of the delay offset this, however, will not automatically lead to an improved accuracy of this measurement of speed of light.

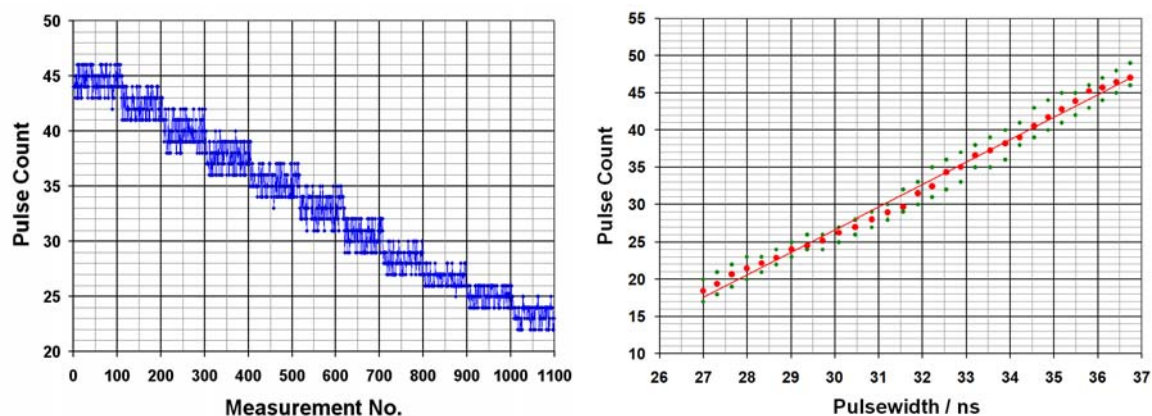


Figure 6. TDC-counts as a function of reflector displacement (left) and calibration

A Current Research Application

In order to stimulate increased interest we show our students that the technique just learned is used in the context of current research. Within the Ko-PER project of the German research

initiative Ko-FAS [10], we use LIDAR-systems to detect vulnerable road users at intersections with the aim to identify critical situations, warn drivers and thus increase road safety. Figure 7 illustrates the principle. Four laser beams of a commercial laser scanner (SICK AG) scan the scene (left side). The LIDAR systems deliver angular and distance values for every reflecting object which is mapped onto a street map (right side). The clouds of reflecting points can be used to directly classify objects [11] or to generate hypotheses for video-based pattern recognition [12].

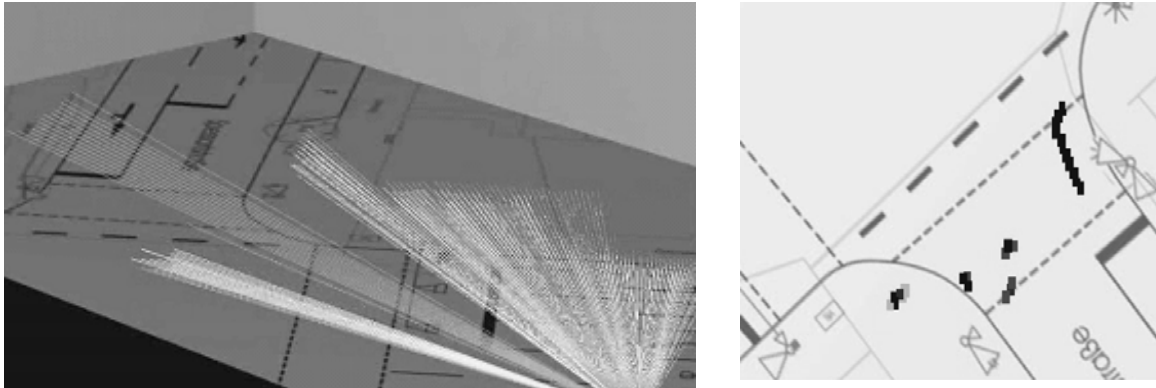


Figure 7. Current industrial research: we detect and classify road users at an intersection

LEARNING OUTCOMES AND EVALUATION

On a yearly basis all courses described above are evaluated by students. We examine the learning outcomes for every course. Table 3 summarizes the results of attained main learning outcomes of our presented concept (column 3) compared to those of the complete course (last column).

Table 3
Learning Outcomes

Course	Main intended learning outcomes of our presented concept	Attained percentage presented concept	Attained percentage overall
Physics 1	Physical design of a time-of-flight measurement including RADAR, LIDAR; Evaluation of resolution, accuracy, sensitivity	72	65
Electronic Devices	Calculation of propagation delay; TDC circuit design	80	72
SPICE	Simulation of propagation delay and TDC circuitry	91	91
Chip design	Layout of a CMOS pulse shrinking delay line	71	71
Lab. Project	Design, realize and evaluate a microcontroller circuitry for TDC or a TDC-based sensor	86	86

Within the physics course we show about 90 experiments. The speed of light experiment always is ranked under the top ten by our students. Within the electronic devices course we

present about 20 demonstrations, where the TDC experiment in conjunction with a research application always ranks first. The acceptance of the concept is above 90%. This fairly well coincides with our observation, that the TDC-specific results of examination are better than the overall mean. The students are encouraged, to place comments in their evaluation. We started to introduce TDCs in our didactical concept five years ago and we never got a negative comment on it. The respective experiments are often characterized to be excellent.

SPICE, Chip Design and Laboratory Project are optional courses. Most often students that elect these courses ask for a bachelor-/master-thesis in this domain. Within our open workspace we currently supervise about 15 master students, i.e. about 20 % of the master students of the engineering faculty. 60% of them do applied research on chip or FPGA-circuit design of intelligent sensors, which shows the interest in microelectronics.

CONCLUSION

We present a novel didactical concept for undergraduate teaching of microelectronics, its learning objectives and the achieved learning outcomes. In this context we introduce an experiment using a CMOS cyclic pulse-shrinking time-to-digital-converter (TDC) in order to directly measure the speed of light. The design of the experiment and of a TDC for educational purposes is described in detail. The atmosphere during the lectures, the questions of the students and the evaluation of the courses show that the measurement of the speed of light on the tabletop together with the explanation, how the electronics work, with the perspective to design a respective chip and with the demonstration of a current research application which may save human life fascinates our students. Partly we refer this fascination to the fact that we present a measurement of a basic physics quantity, which is far beyond the acquisition capability of the human sense organs. We also observe a similar effect when we present scanning tunneling microscopy on the tabletop, however in the students' opinion, the speed of light measurement using the TDC ranks better.

The students' evaluation of the courses shows that the acceptance is above 90% and the TDC-specific results of examination are better than the overall mean. We observe strong interest in a bachelor-/master-thesis in this area of work. Based on these data we conclude that we succeeded in boosting students' enthusiasm for the field of microelectronics within our engineering faculty.

ACKNOWLEDGEMENTS

This work partially results from the joint project Ko-PER, which is part of the project initiative Ko-FAS, and has been funded by the German *Bundesministerium für Wirtschaft und Technologie* (Federal Department of Commerce and Technology) under grant number 19S9022B. Furthermore, the support of the *Bayerisches Staatsministerium für Wissenschaft, Forschung und Kunst* in the context of the *Forschungsschwerpunkt Intelligente Sensorik* at the University of Applied Sciences Aschaffenburg is gratefully acknowledged.

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Ulrich Brunsmann and Konrad Doll promote the integration of industrial research and project-based learning into the undergraduate teaching program. They share the research interest in Intelligent Sensors and Advanced Driver Assistance Systems. Several of their master students received an IEEE Best Student Paper Award.

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CDIO EXPERIENCE FOR NEW FACULTY: INTEGRATING CDIO SKILLS INTO A STATISTICS MODULE

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Sin-Moh Cheah

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ABSTRACT

Over the past three years, various CDIO skills such as teamwork and communication, personal skills and attitudes (e.g. critical and creative thinking, holding multiple perspectives) have been introduced into various technical modules for the Diploma in Chemical Engineering (DCHE) in Singapore Polytechnic. Skills in conceiving, designing, implementing and operating a process, product or system using chemical engineering principles have also been integrated in the three-year curriculum.

As part of its CDIO implementation plan, the course management team for DCHE is integrating other CDIO skills such as experimentation and knowledge discovery, and professional skills and attitudes (e.g. ethical practice) into the curriculum.

In this paper, we will be discussing the CDIO experience of a new faculty and how this is achieved through a professional development programme to support the initiative. The programme starts with enrolment of a new faculty into a Certificate in Teaching (CT) course, to be completed within one year. A key feature of the CT course is the need for a new faculty to conduct an action research project as partial fulfilment of the course.

Specifically, this paper focuses on the action research project of a new faculty to introduce suitable CDIO skills into a Year 3 module entitled *Quality Management and Statistics*. The main CDIO skills introduced are experimentation and knowledge discovery, whereby students are required to formulate hypotheses in verifying experimental results under a simulated real-world task scenario in a laboratory. The students need to carry out a series of experiments coupled with statistical analyses to either confirm or nullify the hypotheses. Based on the analysis of their results, the students are also expected to make relevant inferences, and provide suggestions/solutions to resolve the problem in the simulated task scenario.

This paper presents the approach taken in conducting the action research and shares preliminary students' experience in learning the module, particularly in forming their hypotheses. The new faculty's own reflection of his experience in re-designing the learning tasks using CDIO will also be presented.

KEYWORDS – Action research, chemical engineering, CDIO Skills, professional development, integrated curriculum

INTRODUCTION: DESIGNING THE NEW FACULTY LEARNING EXPERIENCE

The Diploma in Chemical Engineering (DCHE) program in Singapore Polytechnic (SP) adopted the CDIO framework as the basis for its curriculum since 2007 (Cheah, [1]). Over the last several years, various CDIO skills such as teamwork and communication, personal and professional skills and attitudes, critical and creative thinking, etc have been introduced in various core modules in the 3-year diploma program (Cheah and Sale, [2]). Skills in conceiving, designing, implementing and operating a process, product or system using chemical engineering principles have also been covered (Cheah and Ng, [3]).

In order to sustain the CDIO capability of the faculty, especially over the past 3 years where many new faculty had joined the institution; the DCHE Course Management Team (CMT) has collaborated with the Department of Educational Development (EDU) to introduce them into the CDIO engineering educational framework. This becomes part of the DCHE's faculty professional development (PD) program. Part of this PD program is the Structured Mentoring Program (SMP) introduced by Cheah and Singh [4], shown in Figure 1 where the Certificate in Teaching (CT) course, among other approaches, is used to introduce new faculty to DCHE.

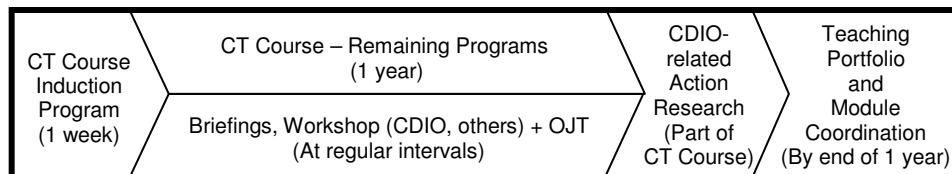


Figure 1. Structured Mentoring Program (SMP) framework for DCHE

The SMP serves to engage new faculty in a multi-prong approach to “jump start” their CDIO competency. A key feature of the initiative is the setting up of a Teaching and Learning (T&L) Unit staffed by experienced CDIO implementers (known as CDIOers) serving as Academic Mentors to new faculty. The CMT and T&L Unit have identified the action research project in the CT course as a useful means to introduce them to CDIO. Under the new PD initiative, the CMT undertakes a more proactive role by working closely with both the new faculty and EDU education advisor in completing the action research project. This essentially entails that we align the CDIO requirements with the action research project executed by the new faculty under the guidance of an experienced “CDIOer” and EDU education advisors.

In this approach, a new faculty undergoes a parallel track of coaching and mentoring by both the Academic Mentor and EDU education advisor. Over the course of a year, the new faculty proceeds to complete his/her CT course, while at the same time being mentored on how to become an effective teaching professional.

The SP Certificate in Teaching (CT) Course

New faculty to Singapore Polytechnic are typically hired from the relevant industries. Many of them lack practical teaching experience. To better prepare them for the academic environment, the new faculty are required to complete a Certificate of Teaching (CT) course over a 12-month period. The first segment is a 5-day induction program which they are supposed to complete before they are allowed to teach. At the end of the 5 days, they are then deployed into full-time teaching. The induction program serves to equip a new faculty with some basic pedagogic skills

before he/she begins teaching, and make for a smoother (hopefully) transition from the industry to academia.

The rest of the CT course is spread across the entire academic year, which covers topics such as writing good learning outcomes, designing active learning activities, designing assessments, etc; all carefully designed to hone a new faculty's pedagogic literacy. A new faculty, who would have started teaching by then, attends various remaining segments of the CT course during timetabled hours.

One major highlight of the CT course requires the faculty to design and execute an action research project. The main aim is to encourage a faculty to be able to reflect critically on his/her practices (Schon, 1983, [5]). One cannot deny that new teachers are constantly gaining new experiential insights as they grapple with challenging teaching and learning situations. During such episodes, many teachers will question their pedagogic abilities and efficacy (Cady et al, [6]). If action research is executed properly in a collaborative environment, it will allow new teachers to learn from the expertise of their colleagues while at the same time honing their own pedagogic literacy and practice. Action research is meant to be non-threatening and non-evaluative. More importantly, action research allows the quality of a faculty's reflections and actions "to integrate concrete teaching experiences, models, and strategies of others, and principles of research in teaching into an integrated whole" (Haley, M et al, [7]). This will, we believe, lead to better teaching and learning effectiveness and an increase in self efficacy which would suggest that the learning experience of our students will be enhanced.

The CT course is conducted by EDU education advisors, and requires frequent meetings between the new faculty and the education advisor to reflect and discuss progress of his/her work. All CT participants are then expected to showcase their work including the action research project they conducted in a Teaching Portfolio.

Mentoring by Experienced CDIOers as Academic Mentors

The Academic Mentor coaches new faculty via a series of briefing sessions, on diverse topics starting from the SP Education Model, DCHE course philosophy, and of course, the CDIO Framework. The new faculty are briefed on the "nuts and bolts" of CDIO, including the changing educational landscape leading to the adoption of CDIO, the rising importance of chemical product design, application of the 12 CDIO Standards in the context of polytechnic education, etc. The Academic Mentor also arranges for the new faculty to attend workshops on underpinning knowledge of CDIO skills conducted by EDU education advisors.

Supplementing such briefings are on-the-job (OJT) training for the new faculty, usually in the form of pairing new faculty with an experienced CDIOer in the facilitation of laboratory activities infused with CDIO skills. Here the new faculty gets to understand first-hand how the various concepts learnt in the CT course are translated into practice in the chemical engineering context and develops a deeper understanding of the CDIO approach.

The new faculty (who is the first author of this paper) is also briefed on the approach taken by DCHE to integrate a selected CDIO skill throughout its 3-year curriculum. The "standard" DCHE CDIO integration model as shown in Figure 2 (Cheah and Sale, [2]) serves to systematically introduce various CDIO skills into selected core chemical engineering modules. In DCHE curriculum, students progress through their years of study by following a stage (semestral) system where they are expected to do and complete certain modules at a particular stage before they are allowed to move on to the next stage. Broadly, the approach advocates

introducing and teaching students specific skills in Year 1 to create the necessary awareness, which are then extensively practiced in Year 2. By Year 3 they are expected to be able to utilize the skills where appropriate and display the required skill transfer, for example, by applying them in other core modules, as well as through the execution of their final year capstone projects.

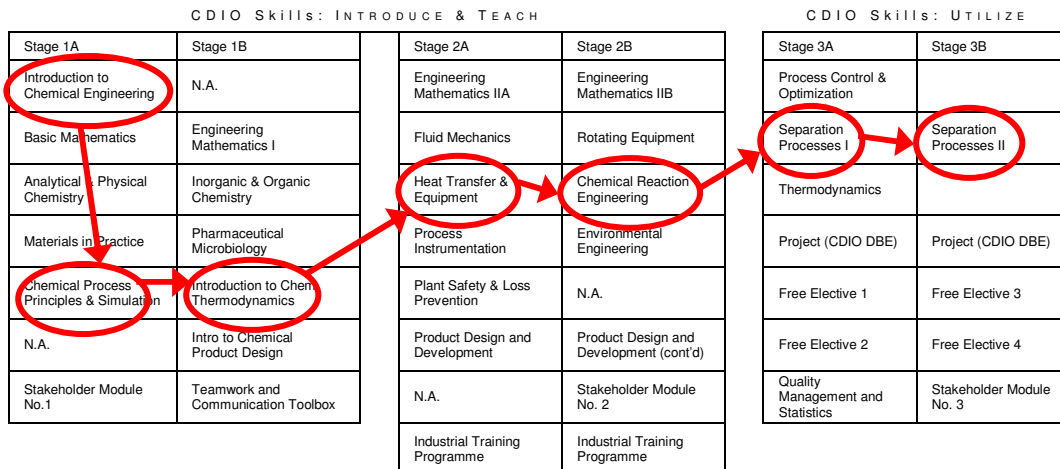


Figure 2. Integrating CDIO skill across a three-year DCHE curriculum

DEVELOPING NEW FACULTY CDIO COMPETENCY: INTEGRATING CDIO SKILLS INTO A STATISTICS MODULE

As shown in Figure 1, the outcome of the completion of the new faculty's CT course is a Teaching Portfolio showcasing his action research work. In this case, the new faculty has been tasked to teach the Year 3 core module *Quality Management and Statistics*. The Academic Mentor works closely with the new faculty in identifying a suitable component of his module materials for integrating selected CDIO skill(s) as well as the appropriate CDIO standards. The team then discusses with EDU education advisor the feasibility and possible topics for action research. The learning activity re-design effort follows the now-familiar approach employed in DCHE: starting with writing clear learning outcomes of student learning (Sale and Cheah, [8]), using scenarios to provide real-world context to student learning (Cheah, [9]), and crafting active, experiential learning activities to engage them.

Evaluating Students' Experience through Action Research

Our discussion on possible topics in the module leads us to decide that "Experimentation and Knowledge Discovery" can be introduced. An assignment for students to practise these skills can be designed that also serves as the basis for the new faculty's action research project.

The main research objectives of the project would include the following:

1. To probe the proficiency of students in transferring and applying knowledge, specifically in terms of hypothesis formulation and experimentation, gained from *Bioanalytics* module, a technical Year 2 core module, to the Year 3 non-engineering *Quality Management and Statistics* module.

2. To evaluate the effectiveness of the real-world scenario-based assignment in enhancing students' learning experience leading to a deeper working knowledge of the module's technical fundamentals.

The new faculty worked closely with both the education advisor and Academic Mentor in designing the learning task for the assignment, oversaw its execution and followed up on its evaluation; thereby developing his own competency in CDIO.

Description of Learning Task

The key feature of the learning task is that we designed it from the start to satisfy several CDIO standards, in particular Standard 3 "Integrated Curriculum", Standard 7 "Integrated Learning Experiences" and Standard 8 "Active Learning". We made use of an existing laboratory activity from another Year 3 module *Separation Processes* that the same cohort of students taking the *Quality Management and Statistics* module is required to complete.

As noted above, the main CDIO skills selected for introduction are "Experimentation and Knowledge Discovery". Other supporting CDIO skills emphasized include teamwork and communication, and personal skills and attitudes.

The CDIO skills of "Experimentation and Knowledge Discovery" had been introduced earlier to DCHE students in another Year 2 core module *Bioanalytics*. In the *Bioanalytics* module students are guided in the approach to formulate hypotheses and test them out by performing experiments in the laboratory. Hence, the students taking the module *Quality Management and Statistics* should not find the concepts of hypothesis formulation and its verification via experimentation unfamiliar.

When it comes to designing the activity for Year 3; consistent with the approach outlined in Figure 2; the team then decided to challenge the students further by requiring them to think and identify some possible issues in a simulated real-world task scenario designed by the team, followed by the formulation of the relevant hypotheses which would then be put to the acid test via a series of experiments planned and designed by the students themselves. This would not be possible without fundamental knowledge of the various chemical engineering principles which the students would have learnt in Years 1 and 2.

Specifically, in the laboratory activity for the *Separation Processes* module, students are required to make use of pycnometers (more commonly known as S.G. bottles) to determine the composition of a given ethanol-water mixture. Pycnometers are simple lab devices used to determine the density of a liquid. They are usually made of glass, matched with a uniquely close-fitting glass stopper with a capillary tube through it. The common sources of errors while using a pycnometer include the mistaken use of a non-matching pycnometer-stopper set and the mishandling of operators while drying the external surface of the pycnometer with wipes.

The team then introduced an assignment for the *Quality Management and Statistics* module that requires students to carry out more experiments on the use of S.G. bottles. Hence, the students can have more opportunities, in an active and experiential manner, to explore the use of S.G. bottles subjected to different experimental treatment combinations. The authors felt that a real-world scenario-based assignment would allow learning and development of the students to fill in the gaps between engineering education and real-world demands on engineers, which is the vision of CDIO educational framework.

The simulated scenario requires the students to role-play as a group of scientists working in a laboratory, which is owned by a local company whose main business is ethanol production. The company received complaints about sub-quality ethanol from its overseas customers and had to bear a huge loss due to compensations. The group of scientists was tasked to investigate the root cause of some erroneous ethanol purity testing results. To bring the learning task to the next level of challenge for the Year 3 students, the scenario was complicated with a number of “distractors”, which are factors deemed to be insignificant in causing the erroneous testing results, to “mislead” them. The students (lab scientists) are expected to investigate and analyze the problem and propose at least two feasible hypotheses, after which, they will either confirm or nullify the hypotheses by carrying out a series of experiments involving S.G. bottles coupled with statistical analyses. By applying selected statistical analysis tools, the students do not only gain better appreciation of the accuracy of results obtained, but also a deeper internalization of the concepts covered. Through this assignment, we also hoped to achieve greater integration between the two modules.

Evaluation Methodology

Multiple sources of data collection on the students’ learning experience were employed so that the results can be validated. Firstly, the faculty captured his on-site observation into a journal which he kept throughout the conduct of the student assignment. Next, a survey questionnaire was administered at the end of the assignment; to capture the impressions of all the students. Two types of questions were asked for the survey questionnaire: (a) One which the students gave their responses based on the 5-point Likert Scale where “1” denotes “Strongly Disagree” and “5” denotes “Strongly Agree”; and (b) Open-ended questions which the students gave brief opinions on their learning experience. Lastly, a focus group discussion was organized with selected students to zero in on specific issues and to probe the students’ experience further.

RESULTS AND DISCUSSION

A total of 54 Year 3 students taking the module *Quality Management and Statistics* were invited to participate in the survey questionnaire. Of the students who were invited, 47 responded to the survey questionnaire, with a response rate of 87%. The focus group discussion was carried out with a group of 12 students. The following sections presents the insights gleaned from the student feedback and the faculty’s own reflection.

Students Learning of the Module

Generally, the students agreed that the real-world scenario-based assignment allowed them to think more critically to identify the hypotheses to be tested, with a mean score of 4.13 ± 0.77 out of 5.00 and 90% of the students responded favourably on the Likert Scale (“Agree” and “Strongly Agree”). This is confirmed by the faculty’s own observation as well as during the subsequent focus group discussions.

An example stands out during the focus group discussion where one of the students emphasized that she thought the assignment was fun as it required her group to manage their own time, team mates and resources just like working individuals do. She enjoyed having more liberty in carrying the tasks and taking more control of them. Some other student responses were as follows:

Liked the way it was carried out, i.e. the consultation with the lab manager (lecturer) to clarify issues and propose hypotheses. It's more real.

This assignment was unlike some of the "*sien*" (means boring in local terms) practicals. More fun to work with.

It allowed us to think out of the box. Future assignments should be done this way.

These findings suggest that future assignments and classroom activities may be designed in a similar manner to better engage students.

What the new faculty also found most encouraging is the following statement made by one of the respondents:

The scenario presented us with several factors. Some could be more significant, some not. We needed to think and analyze the situations critically and weigh the factors using our prior knowledge to eventually make decisions about which hypotheses to test out. I enjoyed the learning journey.

This provides an indication, if not an assurance, that real-world task scenarios are indeed an effective means to enhance the students' learning experience. Moreover, it also confirms that knowledge of chemical engineering principles is vital and plays an important role in allowing the students to make sound decisions.

When asked if they were able to effectively apply the statistical tools in the assignment, the students responded positively to it with a mean score of 4.15 ± 0.69 . In addition, all participants from the focus group discussion acknowledged that it is a more motivating experience to apply statistical tests on their own data instead of a given set of experimental data, such as that during tutorials. Experimental data from their own experimentation gives them a sense of ownership and they will have the urge to find out significance of their data using statistical tests, as data on its own carries no meaning.

Teamwork and communication remains as a crucial CDIO element to get the tasks carried out efficiently and effectively. 70% of the questionnaire respondents gave a Likert Scale rating of 4 or 5, respectively for "Agree" or "Strongly Agree", with a mean score of 3.91 ± 0.87 . At the time the assignment was taking place, it was the students' final semester in SP prior to their graduation, it was also the period where they were packed with a lot of assignments, reports, and not to mention, final year projects and examinations, this made teamwork and communication even more important as they really had to communicate and work collaboratively to ensure all tasks were completed for a guaranteed graduation.

Faculty Reflection

The new faculty, who was a postgraduate engineering student prior to becoming an academic in SP, perceives himself as one who was brought up and trained by the traditional teaching and learning approach, namely, teacher-centered approach. It would take a fundamental shift in the new faculty's mindset to effectively address curriculum design and deployment as a new member in the Diploma in Chemical Engineering, which had adopted the CDIO framework as the basis for its curriculum. Specifically, some of the challenges he had initially faced were:

1. Developing an understanding in CDIO skills and their potential infusion in modules.

2. Establishing competency in designing module materials and activities within a relatively short period of time.
3. Transition of mindset from a predominantly teacher-centered approach to a more student-centered learning focus.
4. Balance the numerous demand of an academic – juggling between teaching, CT course, and other administrative requirements.

Having recently completed the CT course and the action research project under the DCHE SMP (Figure 1), the new faculty felt that the mentoring process had, to a large extent, not only helped him ease into his new role as a teaching professional, but also an excellent avenue to fast-track his CDIO competency development. In the new faculty's opinion, attending various OJT trainings alongside an experienced CDIOer is an excellent way for him to pick up the "nuts and bolts" of CDIO in a relatively short time of one year. He regarded himself as a "clean sheet" to CDIO before joining SP, but after a year of CDIO immersion under the SMP, he felt that he had gained a better understanding of CDIO standards and skills. The development of CDIO competency was further supported by various EDU- or Diploma-based workshops, often jointly conducted by both EDU education advisors and academic mentors; who worked together to customize the workshops by contextualizing the learning with relevant examples in chemical engineering. In addition, the "CDIO Sharing Sessions" (organized by the DCHE CMT) to promote learning amongst colleagues have also been an important element to growing his CDIO competency.

For example, the new faculty now has a good understanding of "Integrated Curriculum" (CDIO Standard 3), "Integrated Learning Experiences" (CDIO Standard 7) and "Active Learning" (CDIO Standard 8), in particular, designing simulated "authentic" real-world learning task espoused by these standards. The new faculty can now better appreciate the importance of explicitly teaching teamwork and communication to students, again, in a way that reflects the real-world environment under which today's graduates are expected to participate in. Not only were the students more motivated to learn the module, they were also able to transfer the CDIO skills developed earlier and apply them in the current module.

In addition, the new faculty is able to put into practice much of what is being taught in the CT course, by collaboratively defining, designing, implementing and eventually using learning activities for the module *Quality Management and Statistics* he is currently coordinating.

The new faculty also sees two benefits of the DCHE's SMP. Firstly, the SMP provided a systematic pathway of progressive learning and development leading to the execution and completion of his action research project, and then his CT course completion. In the aspect of professional development, the new faculty felt that the SMP activities had helped him grow in his teaching profession via the conduct of the action research project. The provision of mentoring activities was well-coordinated and adequate. Particularly, the ideal timing of the CDIO action research project which came right after the action research workshops by EDU had allowed him to embark on the journey more confidently. "Well begun is half done", this phrase aptly describes the timely and coordinated execution of the project. He now has a deeper understanding of what action research is for, namely, to encourage teaching personnel to consistently and systematically develop a question, gather data, and then analyze the data to get insights to improve their practice (Gilles et al, [10]). The importance of action research in promoting the growth of new teachers is emphasized by Ginns et al, [11], who maintained that it could:

... empower teachers to examine their own beliefs, explore their own understandings of practice, foster critical reflection, and develop decision making capabilities that would enhance their teaching, and help them assume control over their respective situation. (p.129)

This is further supported by Darling-Hammond and Bransford [12] who summarize that:

Emerging evidence suggests that teachers benefit from participating in the culture of teaching – by working with the *materials and tools of teaching practice*; examining teaching plans and student learning while immersed in theory about learning, development and subject matter. They also benefit from *participating in practice* as they observe teaching, work closely with experienced teachers, and work with students to use what they are learning. (p.404)

This reflective practice had allowed the new faculty to critically reflect on the changes he made to the learning activity and the students' responses from the questionnaire and focus group discussion could be further explored for the continual improvement of the module as well as his teaching practice.

Secondly and most importantly, the new faculty felt that the work done, apart from benefiting himself, had also brought improvement and enhancement to his students' overall learning experience. That was the very reason why the new faculty chose to join the teaching profession in the first place, and that is to be able to make a difference in students and to inspire youth. Today, we are witnessing the paradigm shift away from teaching to an emphasis on learning. The transition has encouraged power to be moved away from the teacher to the student (Barr and Tagg, [13]). The teacher-centered transmission of information, such as lecturing, has been increasingly criticised and this has paved the way for a widespread growth of student-centered learning as a substitute. Harden and Crosby [14] describe student-centered learning as focusing on the students' learning and "*what students do to achieve this, rather than what the teacher does*". Gibbs [15] draws on similar concepts when he explains that student-centered learning places emphasis on learner's activity rather than passivity. From his personal experience both as a student for more than 15 years and an academic for 1 year, the new faculty cannot agree more that learning should place students on the center stage where learning can be maximized and is therefore more meaningful. As Edwards [16] illustrates in more technical terms:

Placing learners at the heart of the learning process, assessing and meeting their needs, is taken to a progressive step in which learner-centred approaches mean that persons are able to learn what is relevant for them in ways that are appropriate. (p.37)

To the new faculty, it is an enjoyable experience to see how students like his teaching and learning activities, and exit the classroom with new knowledge gained.

SUMMARY AND CONCLUSIONS

The administration of the real-world scenario-based assignment has enhanced students' learning with the application of CDIO skills, i.e. "Experimentation and Knowledge Discovery", teamwork and communication, and personal skills and attitudes. The setting of a real-world scenario lends the learning activity a sense of authenticity which allows a deeper student appreciation of the module's technical fundamentals. Nonetheless, good teaching practices are not invariant with time, which simply means they are subject to change. Hence, reflective practices and continual improvements are essential for faculty, and this is where action research fits nicely into the scene. Taken together, the Structured Mentoring Program (SMP) is able to introduce new faculty into the Diploma in Chemical Engineering and systematically prepares them for their teaching duties. In view that a new faculty is often laden with various administrative duties besides teaching, it should therefore be noted that careful planning of mentoring activities is vital to a new faculty such that a fine balance can be struck between CT course, SMP and other tasks.

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Biographical Information

Poh-Hui Chua is a new faculty in the Diploma in Chemical Engineering (DCHE), Singapore Polytechnic. He is currently lecturing on topics including introduction to chemical engineering, and quality management and statistics. Besides teaching, he was also given the opportunity to serve as a teacher advisor for the DCHE Student Chapter, a facilitator in the Polytechnic's multi-disciplinary projects, while at the same time, under-studying project-based modules offered by experienced CDIOers.

Sin-Moh Cheah is a chemical engineer turned academic. He is the Deputy Director in Singapore Polytechnic, overseeing various applied sciences diploma, including the Diploma in Chemical Engineering. He has lectured on various topics including chemical engineering principles, separation processes, heat transfer and equipment, and chemical reaction engineering. His current portfolios include curriculum revamp, academic coaching and mentoring, and using ICT in education. His current scholarly interests are learning pedagogy, curriculum re-design and program evaluation. He held various positions in Mobil Oil Singapore Pte Ltd (now part of ExxonMobil) prior to joining Singapore Polytechnic.

Mark Nivan Singh is an education advisor with the Department of Educational Development. He is the co-ordinator of the Certificate in Teaching Programme for new lecturers and thinks he has the best job in the polytechnic. Besides running workshops for new lecturers, he is also involved in helping staff integrate various educational initiatives such as CDIO into the various diplomas. His current interests include professional development of staff and new pedagogy.

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SUSTAINING CDIO CAPABILITY: PROFESSIONAL DEVELOPMENT FOR ENGINEERING FACULTY

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ABSTRACT

The Diploma in Chemical Engineering (DCHE) adopted the CDIO framework as the basis for its curriculum since 2007. Over the last several years, specific CDIO skills have been introduced in various core modules in the 3-year diploma program.

The course management team has recognized the need to continually sustain the CDIO capability of its faculty. The paper describes the efforts undertaken by the course management team to provide the necessary deep learning (Marton, [1]) of the CDIO initiative to new faculty and returning faculty. The goal was to get the new and returning faculty to learn about the CDIO initiative in the same manner as the initial “pioneering” batch of CDIO implementers, known as “CDIOers”. This paper first discusses professional development of the faculty with regard to CDIO skills in the polytechnic which, in the author’s view, is insufficient in its present format to sustain the development of faculty competence in CDIO skills.

Learning from identified gaps in the present arrangements, this paper will argue for an integrated approach to the professional development of faculty by integrating faculty training, pedagogy and curriculum development. This is to be further supported by getting faculty to participate in reflective practice upon completion of a CDIO assignment.

The paper then describes approaches taken by the course management team to initiate the faculty CDIO skill acquisition process. The advantages and disadvantages of the various approaches will be discussed, as well as reflections by faculty on their usefulness.

Finally, the paper will discuss the issues and challenges faced by the course management team and mentors in adopting the approaches. We will identify some key learning points and outline future directions in facilitating a more effective approach towards professional development in this area.

KEYWORDS

Faculty on-the-job training, chemical engineering, CDIO skills, professional development framework

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) adopted the CDIO framework as the basis for its curriculum since 2007. Subsequently, over this duration, a systematic approach for integrating CDIO skills into the DCHE curriculum has emerged, as accounted for by Sale and Cheah [2], Cheah [3], and Cheah and Sale [4]. Various CDIO skills such as teamwork and communication, critical and creative thinking, displaying multiple perspectives (collectively known as “CDIO Skills” in this paper) and skills in conceiving, designing, implementing and operating a product, process or a system (collectively known as “C-D-I-O Skills”) have been introduced in various core modules in the 3-year diploma program ([5], [6], [7], [8]). The CDIO framework has also been used in final year student capstone projects ([9], [10]) as well as an overseas community service effort ([11]).

In the “formative” years of integrating CDIO into the curriculum, participating faculty have acquired the necessary deep understanding of the various skills through producing a customized SP-CDIO syllabus, as well as the related underpinning knowledge for such skills. The faculty also conducted an extensive gap analysis and mapped the CDIO skills into the core modules and also designed various learning activities and assessment schemes for each skill. Since rolling out the CDIO chemical engineering curriculum, some 14 core modules (out of a total of 36 modules in the whole diploma) have CDIO and/or C-D-I-O skills infused in the chemical engineering curriculum.

New faculty (those joining the Polytechnic in the last 12 months or less), however, did not have the opportunity to participate in the extensive curriculum revamp compared to the “pioneering” batch of faculty, by virtue of them joining the polytechnic after the initial implementation. The same can also be said of other existing faculty, who did not initially actively participate, either choosing to watch on the sidelines wondering if this was going to be a passing “fad” or faculty who missed out on the opportunity due to other reasons such as study leave or maternity leave. We have termed them “returning faculty” for the purpose of this paper.

Without an on-going professional development program to introduce them to the “nuts and bolts” of CDIO, these faculty will simply “inherit” one or more CDIO-enabled modules and would be executing the various activities without the deep internalization mentioned above. At best, the significant learning experience that would have been gained behind the curriculum re-design effort is largely lost. At worse, the learning experience that the students may go through may not reflect the efforts of the CDIOers in improving the teaching and learning experience for our students.

THE CURRENT SYSTEM FOR PREPARING NEW FACULTY

The current professional development in the polytechnic, in the author’s view, is insufficient in its present format to sustain the development of faculty competence in CDIO skills. New faculty are required to go through a ‘standard’ Certificate in Teaching (CT) program upon joining the institution. The CT program is administered by the Department of Educational Development (EDU), and taught by experienced educational advisors. The CT program consists of various segments to be completed by a new faculty over a one-year period. The first segment is a 5-day induction program to equip a new faculty with basic knowledge of pedagogy and teaching skills, before one starts teaching in the classroom. However, because each diploma program in SP has customized the CDIO programme to suit its own needs, the CT program, which is meant to be a generic programme that covers pedagogic literacy, does not lend itself to cover the various diploma’s CDIO needs within its limited timeframe.

Hence, the burden of “CDIO induction” thus falls onto the shoulders of each of the diploma’s Course Management Team (CMT). Often, the CMT is already very pre-occupied in the day-to-day running of the diploma to be able to effectively engage any new or returning faculty in building up his/her CDIO competency.

With the adoption of CDIO, EDU has also developed various workshops on CDIO, such as understanding underpinning knowledge of CDIO skills. These workshops can be customized somewhat to the needs of each diploma, but requires the input from the relevant CMT to provide the necessary context under which a given CDIO skill can be integrated. This placed additional strain on an already-busy CMT.

Also, even though the institution does encourage and support faculty attending professional development programmes, often faculty tend to focus on technical competence of their profession, resulting in inadequate attention being given to learning CDIO skills. More importantly, the process of engaging faculty in professional development is often hampered by competing initiatives requiring the immediate attention of lecturers.

ENHANCED INTEGRATED PROFESSIONAL DEVELOPMENT OF FACULTY TO ATTAIN CDIO SKILLS

CDIO Standard 9 “Enhancement of Faculty CDIO Skills” calls for the support of faculty to improve their own competence in the *personal, interpersonal, and product and system building skills* described in CDIO Standard 2.

We have proposed an enhanced professional development plan that leverages on the strengths of existing systems and offers an integrated approach to the professional development of faculty by linking faculty training, pedagogy and curriculum development. This is to be further supported by getting faculty to participate in reflective practice upon completion of a CDIO assignment. Schon [12] argues that reflection-in-action or reflective practice comes into play when people deal with “situations of uncertainty, instability, uniqueness and value conflict”. More importantly, Schon also points out that to deal with such situations, one can carry out an experiment which serves to “generate both a new understanding of the phenomena and a change in the situation.” Using Schon’s analytical framework, we are encouraging faculty to engage in Action Research. The framework is shown in Figure 1.

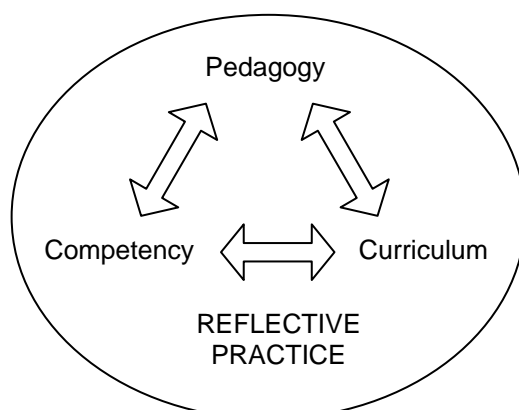


Figure 1. Alignment of Pedagogy, Curriculum and Competency

The DCHE CMT set up a Teaching & Learning (T&L) Unit with the purpose to systematically (i) prepare new faculty to be fully equipped with CDIO know-how and to function effectively as module coordinators, and (ii) enable returning faculty to get up to speed with CDIO and continue their duty as module coordinators. Members of the T&L Unit include experienced “CDIOers” serving as Academic Mentors to help in coaching and guiding both new and returning faculty in using CDIO to revamp their modules. As shown in Figure 1, this requires the 3 parties, namely the CMT, the Training Manager, and the mentors to work closely together to plan out the development program for new and returning faculty.

The DCHE T&L Unit designed a structured mentoring program (SMP) that integrates staff competency development in teaching pedagogy with other personal developments and professional training, by linking curriculum review with pedagogy training needs; and staff development program with curriculum design and development. This is to ensure consistency of curriculum design or re-design using CDIO.

The DCHE SMP for faculty development in CDIO is shown schematically in Figure 2. The top figure shows the induction of new faculty to the CDIO framework through a combination of briefings, workshops and various on-the-job training (OJT) programs. The SMP leverages on the requirement of the CT program that a new faculty must complete an action research project, by requiring the new faculty to base the topic of his/her action research project on CDIO-related initiative. At the end of the CT program, a new faculty is expected to submit a teaching portfolio that would capture the key learning points of the entire CT programme. This serves as a scaffold for faculty in training them to serve as a module coordinator which requires them to oversee the review and development of the module under his/her charge.

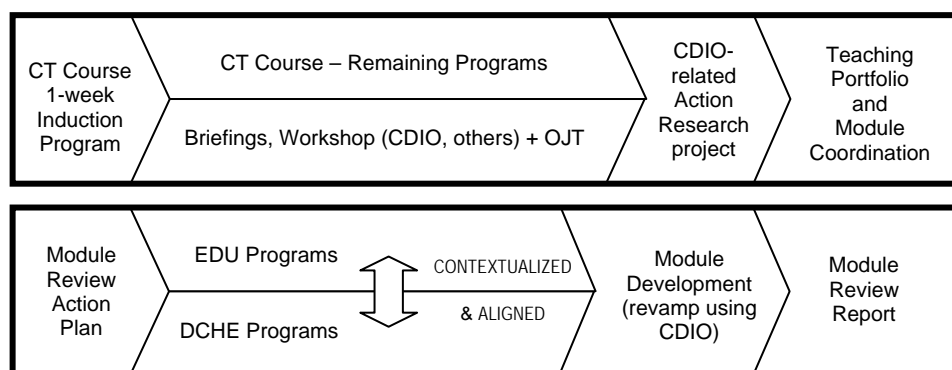


Figure 2. Structured Mentoring Program (SMP) framework for DCHE

The lower figure shows the approach to build up CDIO capability for both new and returning faculty. As module coordinator, a faculty is expected to continually review and improve on his/her module for example based on inputs from external review panel and other stakeholders. Working with the Academic Mentor, the module coordinator formulates the necessary action plan to improve the module. The Academic Mentor then analyzes the potential training needs and in consultation with the training manager, plans and engages the necessary training agency for the required training. The training is customised to suit the unique needs of the course.

PULLING IT TOGETHER

The various CDIO programs can largely be grouped into 2 approaches. The first approach is through a re-visit of the earlier gap analysis, conducted 3 years ago when CDIO was first introduced. Over the years, much has changed and the course management team felt that the time was right to take stock of the curriculum with regards to integration of CDIO into the

modules. The new faculty or returning faculty is paired up with existing “CDIOers” (including the author) who serve as mentors to lead the effort in the second round of gap analysis. The CDIOers first shared the various underpinning knowledge of CDIO skills with the new or returning faculty through a series of briefings such as “*Introduction to CDIO*”, “*CDIO and Chemical Engineering*” (which describes the rationale for DCHE to adopt CDIO), “*SP’s Customised CDIO Curriculum*”, etc. They then attend workshops on “*Understanding Underpinning Knowledge of CDIO Skills*”, and “*Outcomes-based Education*”, which are often jointly conducted by senior education advisors from EDU and DCHE academic mentors. These workshops are often customised to meet DCHE needs with suitable examples and working document that are familiar to faculty. The team then conducted in-depth interviews with other faculty members who had introduced CDIO into their modules. From the gap analysis, the team updates the CDIO skill coverage map for the diploma, and in the process, gained understanding of how CDIO is being introduced into the curriculum.

The second approach was to show the new or returning faculty “the ropes”, by engaging them in on-the-job (OJT) training. For this approach, several methods were employed, such as shadowing more-experienced CDIOers, coaching and mentoring in module development to introduce selected CDIO skill(s), execution of student final year (capstone) projects, and involvement in new CDIO initiatives. This was again achieved via the assistance of selected CDIOers as mentors.

The workflow for faculty engagement in the program is shown in Figure 3. As a new faculty starts his/her teaching career, he/she is put in charge of coordinating a selected module, and may be required in teaching or serve as laboratory facilitator in one or more other modules. The new faculty undergoes a series of briefings and workshops designed to jump start the faculty’s CDIO competency.

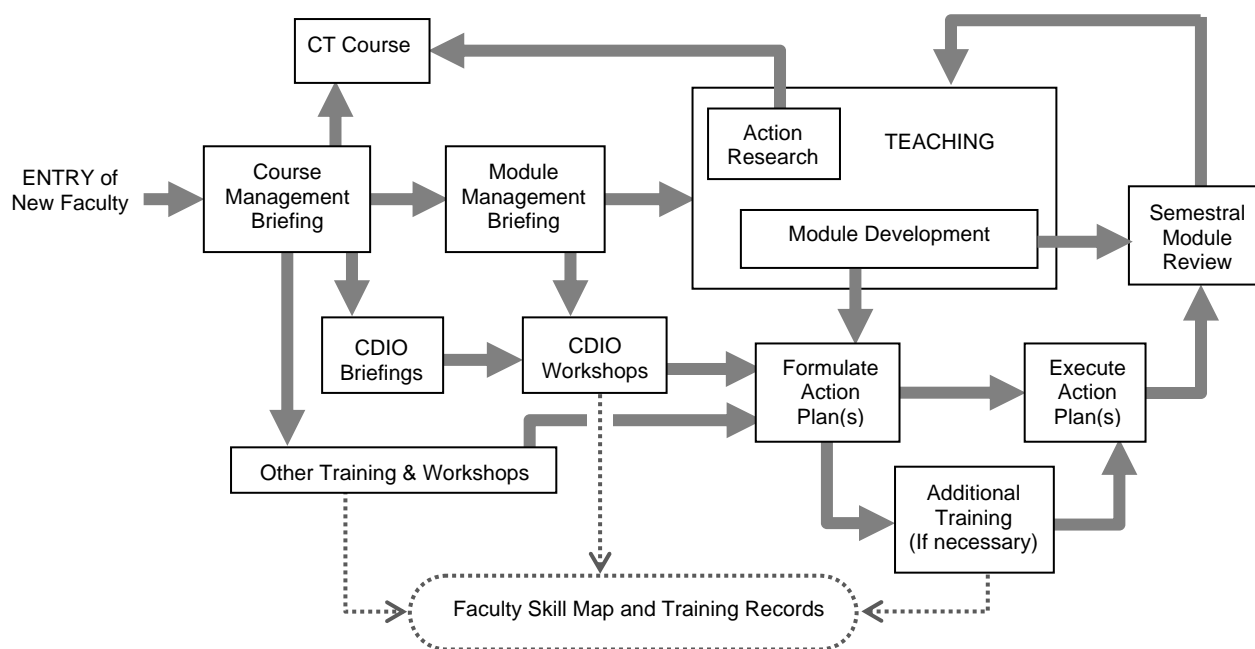


Figure 3. Work Flow for Faculty Engagement in CDIO

Some of the salient features are briefly explained below:

- The Course Manager conducts briefing on overall course management requirements, e.g. module review and development
- The Academic Mentor conducts briefing on the CDIO framework, Standards and Skills, and the underpinning knowledge for the CDIO skills

- The Academic Mentor arranges for existing module coordinator to brief new faculty on fine details of intended learning outcomes of key CDIO activities (lab, assignment, case study, etc) in module(s) the new faculty is taking over or helping out, including CDIO skill coverage map
- The Academic Mentor works with the Training Manager to set up training calendar and timeframe to complete all necessary CDIO trainings

In the first year of the new faculty's teaching career, the Academic Mentor together with EDU's senior education advisor, coaches the new faculty in completing the action research requirement of his/her Teaching Portfolio. An account of this initiative had been covered in a separate paper by Chua et al [13]. Besides the action research, a new faculty also goes through a series of OJT programs to "jump start" his/her CDIO capability.

The preferred method of OJT is by pairing up a new or returning faculty with experienced CDIOer to jointly conduct selected CDIO-enabled laboratory or workshop sessions. The CDIOer provides both on-site coaching and off-site reflection of practice. Where the timetable of the new faculty permits, he/she can also "shadow" and observe a CDIOer conducting laboratory or workshop sessions; and taking down notes, observing the questioning techniques and following-up etc; and conclude with a debrief by the CDIOer.

The Academic Mentors may also sit in the new faculty's CDIO-enabled laboratory or workshop sessions and gives feedback to help improve practice.

Other forms of OJT are also utilized, especially when pairing is not possible. These include, undertaking the supervision of CDIO-type final year capstone projects, designing new CDIO-type laboratory activity (see for example [4], [5]) or assignment (i.e. those requiring students to conduct literature review, critique via a written report, or make a PowerPoint presentation) or new CDIO initiatives by the CMT, such as integrating "*Experimentation and Knowledge Discovery*" into the DCHE curriculum.

The advantages and disadvantages of the various approaches are shown in Table 1 below. Usually a combination of approaches is used. For example, a new faculty can be simultaneously undergoing OJT via pairing and shadowing, and also at the same time, undertake supervision of final year projects. There is also an online tutorial on implementing CDIO for new faculty.

Table 1
Advantages and Disadvantages of Various Approaches

Approach	Advantages	Disadvantages
Pairing	"Live", on-the-spot practice of CDIO skills alongside an experienced CDIOer; shortens learning curve relatively quickly.	Completely engaged with groups within his/her own supervision; unable to fully observe experienced CDIOer in action. Subjected to limitation of time-table planning.
Shadowing	Opportunity to silently observe experienced CDIOer in action; and taking notes of learning points at the same time.	Subjected to limitation of time-table planning. Internalization may not be as deep as the pairing approach, as there is no actual active participation.
Gap Analysis, and curriculum revamp	Can provide high level of appreciation through in-depth study of module's coverage of CDIO skills.	Not effective if a module is already sufficiently CDIO-enabled, as actual participation in revamping the module is low.

Table 1 – cont'd

Final Year Project	Faster for new faculty to internalize CDIO framework, as results is usually observable first-hand in a relatively short time.	Not all projects are amenable to CDIO (e.g. industry-sponsored one with strict protocol to follow), or limited in the type of CDIO skills that can be practiced.
New initiative	“Pioneering spirit” can arouse strong motivation and greater ownership vs. “incremental improvement” in some curriculum revamp effort.	Some sufficient prior experience is needed, which a new faculty may lack; also such opportunity may not be readily available when needed.

Reflections by New Faculty of Learning Experience

At the time of this paper, a total of five new faculty had at various stages completed their CT programs, and participated in various OJT programs outlined above. They were then approached to share their experience with the authors of the paper. A total of 6 questions were asked about their experience on the mentoring programme designed for them. All respondents agreed that the mentoring process has helped them ease into their new role as a lecturer in the school of Chemical and Life Sciences. They also felt that the mentoring activities have helped them grow as lecturers in the school.

When probed further and asked which particular activities were most useful, the new lecturers highlighted the value of the CDIOers who have mentored them, describing them as “adept and very caring.” They feel that the mentors have always helped them and have become, in one staff’s term, their “anchor”.

What the authors have also found most satisfactory is the following comment from one of the new lecturers:

“The perfect timing of AR mentoring which came right after the CT AR Workshops allowed me to practise what was taught in the workshops while the memory was still fresh in mind. The conduct of AR mentoring also fulfils a few purposes at the same time, i.e. completing the teaching portfolio for CT graduation, writing a paper for a conference, and getting a better grasp of CDIO and AR through hands-on practices. I thought that was highly beneficial in view that time is always limited for lecturers.”

This gives us the confidence that tying the Action Research requirement by getting lecturers to work on a CDIO project is an effective way to develop a sound foundation for CDIO implementation. Furthermore, it seems to tie in with Schon’s [12] own observations that “when someone reflects-in-action, he becomes a researcher in the practice context”, not relying on proven methods and received wisdom but developing strategies and theories as s/he goes along. “Thus reflection-in-action can proceed ... because it is not bound by the dichotomies of Technical Rationality.” We intend to fine tune the process even more.

With every new programme, there are also several things which the new lecturers did not like. For example, they pointed out that the mentors who mentored them needed to have mentoring skills such as giving feedback effectively and working well with peers. Another lecturer also felt that due to their heavy workload, he found it tough to follow up on recommended readings as he simply did not have the time.

All respondents however, responded positively when asked if they managed to balance their mentoring activities with the demands of their daily work. They did however offer, in the opinion of the authors, some useful ideas on how the processes can be improved. They felt

that the mentoring needed to be more structured and varied rather than the mentors instructing them what to do. They wanted more useful tools to use and develop as part of their professional knowledge-base. The respondents also felt that by plunging them into the deep end and getting them to work on their Action Research tied to a CDIO idea was the “best way to learn compared to listening”. Another respondent also suggested that mentors work one on one to give more interaction time and also for the newer staff to have a more intimate learning experience. As Bate, Bevan & Robert [14] illustrate in more technical terms:

... people cannot want it until they have tried it. The concrete experience of participating in a movement is crucial, meanings and value being formed after the experience not before it. (p.31)

Similarly, Guskey [15] makes the point that educators do not typically change their own beliefs from most professional development opportunities. Their practice is only likely to change when they see evidence that the change positively affects student learning.

While familiar, the authors have also identified several challenges which dogged the experience.

CHALLENGES

Stuart and Tatto [16] noted that “every initial teacher preparation program has to operate within certain structural and institutional parameters. Decisions have to be made about length and location of the course, its timing within a teaching career, and the place of the practicum. Resource constraints are also relevant to these decisions”. This is certainly true for the DCHE CMT. In the process of implementing its SMP to build up its CDIO capability, the team faced several challenges, and these are briefly discussed below.

Duration of CT Program

The 1-week program is a compromise between manpower needs for deployment as soon as possible, versus a more fully-trained new faculty able to “hit the ground running”, so to speak. Manpower demand is often unpredictable, due to sudden resignation or other factors such as maternity leave; that results in urgent need of new faculty to fill the void. A new faculty, upon recruitment, is required to fill a teaching void almost immediately, leaving very little time for any preparatory work other than the 5-day induction program.

Balance between time for CT course, SMP and other tasks

There is also often insufficient time for a new faculty to attend all the trainings within the first year of his/her joining the Polytechnic. Besides teaching, a new faculty is laden with various committee work and familiarization with administrative demands such as laboratory safety protocols, purchasing procedures, student counselling. This often overwhelms new staff.

Timetabling

Our experience of the past year has proved that it is very difficult to pair-up a new or returning faculty with experienced CDIOers. Various constraints, including the need to block-off selected time slots for the conduct of common modules and key individuals for various committee works meant that the degree of freedom that remains in any timetabling effort is very limited. This is therefore difficult for the CMT to successfully pair-up the teaching team for OJT in CDIO. It is equally challenging to arrange for shadowing of a CDIOer by the new faculty.

Modules already CDIO-enabled

The first set of CDIO skills, such as teamwork and communication, are the “low-hanging fruits” that were already very well embedded into the curriculum during the early days of the revamp exercise three years ago. See for example [5], [6]. Similarly, the C-D-I-O skills also readily lend themselves for integration into various “dedicated” modules such as *Product Design and Development* [7], and *Final Year Project* [10]. These modules have already been infused with the CDIO standards and skills. When the module is passed on to a new or returning faculty, it does not offer much opportunities to introduce any more new CDIO skills.

Lack of Faculty Experience in Certain CDIO Skills

Some CDIO skills (e.g. displaying global mindset, understanding of foreign culture, or technical entrepreneurship) are relatively more challenging for faculty to infuse into their respective modules. This largely reflects the lack of exposure of the part of the faculty themselves, mainly due to lack of opportunity whether in the present appointment or past job experience. It would indeed takes time to build up faculty competency in these areas, requiring a well-planned and effective faculty professional development program.

Lack of Faculty Experience in Reflective Practice and Other Skills

Many of the existing faculty, including some of the experienced CDIOers, have not been trained in reflective practice. Some experienced CDIOers also lacked facilitation skills in coaching and mentoring new faculty. Faculty also lack facilitation skills as well as skills in conflict management.

THE PATH FORWARD: PROFESSIONAL DEVELOPMENT FRAMEWORK

The previous sections outlined the DCHE CMT’s SMP which is aimed at inducting a new faculty in his/her CDIO capability. Looking forward, the CMT has recognised the need to continuously strengthen such capability via an effective professional development (PD) program. Again, to quote Stuart and Tatto [16], who said that “... the professional preparation of teachers is seen in terms of life-long learning, where initial training, induction, and in-service development are seen as part of a continuum”. Figure 4 below outlines a proposed PD framework that ties in capability and competency building of faculty with the long-term needs of the Diploma in Chemical Engineering, consistent with the organizational needs of Singapore Polytechnic.

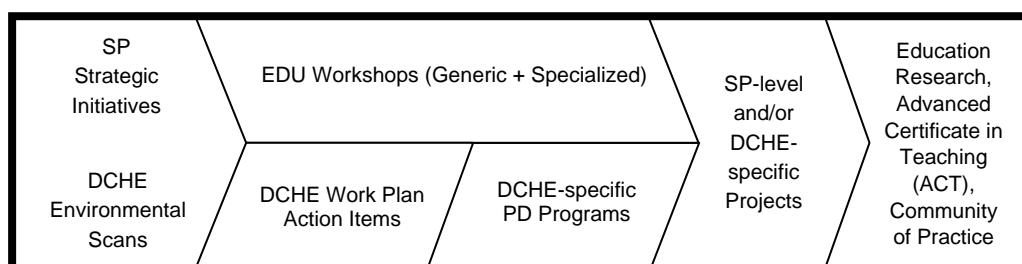


Figure 4. Proposed DCHE Professional Development Framework

The DCHE CMT regularly conducts environmental scans for changes in its operating environment that affects its curriculum, for example, increasing importance of soft skills and chemical product design that led to its adoption of CDIO back in 2007. From the results of the environmental scans, along with SP-wide strategic initiatives (i.e. those impacting all diplomas), the CMT formulates its action items through its annual work plan seminar. From

here, the CMT identifies the specific core competency that faculty needs, for example, skills in chemical product design and sustainable development.

Where competencies can be developed in-house via available EDU programmes, (for example, design thinking) the CMT will again partner with the education advisors and Academic Mentors to jointly conduct the PD programs. Here, as in Figure 2, generic knowledge and skills will be contextualized with examples from chemical engineering. However, for specific programs related to development in chemical engineering (such as process intensification), the CMT with the assistance of the Training Manager will source for the relevant PD programs outside campus.

The long-term goal for the above PD framework is to enable faculty to continually engage in educational research whereby the technical expertise are always developed with a pedagogic mindset; hence ensuring that any curriculum development effort is properly aligned with the CDIO framework. Faculty can further hone their CDIO skills by participating in selected communities of practice, professional development programmes (e.g., in-house Advanced Certificate in Teaching Practice, specialized workshops, etc), and participation in educational conferences both locally and overseas. In their learning journeys, faculty will be encouraged to maintain reflective practice in order to make the necessary transfer of learning to the real world of situated practice.

CONCLUSIONS

There is no consensus on the best way to prepare teachers. Stuart and Tatto [16] noted that “programs evolve, change, and develop out of the local context and in response to the perceived need of the time and place.” This paper has presented a framework for rapidly building up the CDIO capability of new and returning faculty, and has proposed a professional development framework based on alignment with overall institution development needs, program requirements as well as individual faculty’s competency needs. Though based on the experience of the Course Management Team of the Diploma in Chemical Engineering, we believe that the approach is practically useful for others who face similar challenges in attempting to build up the CDIO capability of their faculty.

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Biographical Information

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EVIDENCE FOR EXCELLENCE IN INTERNATIONALIZATION & MOBILITY A SELF ASSESMENT

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ABSTRACT

Internationalization and Mobility (I&M) has become an integrated part of engineering education, making institutions embracing it as a worthy profile in their marketing strategies.

Though most areas of operation at an engineering institution are annually evaluated through systematic quality assurance, their I&M profile seldom is put under scrutiny.

One reason might be that the standard for I&M insufficiently is stated through assessable outcomes and evidence.

The issue of I&M has been propelled onto the agenda of CDIO and proposed at the 6th international conference at Montreal, June 2010, as a 13th CDIO standard (Campbell, 2010). The proposal was thoroughly discussed at various meetings at the conference, in the CDIO regional groups and the CDIO council, which endorsed follow-up actions.

In an effort to support the process, this paper will present a self-assessment of I&M at the School of Engineering, Jönköping University with the ambition to formulate clearer outcomes and evidence for excellence in Internationalization and Mobility.

The self-assessment will follow the general guidelines for the implementation at an institution of CDIO Standards with the involvement of all stake holders. The central question will be: **What are the evidence for a good standard of internationalization at the university?** Information will be taken from both undergraduate and Master students from their evaluation forms and from interviews with the personnel at the International Office and heads of departments. Research will also be made on what is written in the area of assessing Internationalization & Mobility.

Clearly formulated evidence for excellence in I&M and a model of how to constructively assess it in an organization should contribute to the current discussion within the CDIO initiative.

KEYWORDS

Internationalization, Mobility, self-assessment, quality assurance, evidence for excellency

1. BACKGROUND

The last decade has witnessed a sharp increase in international student mobility, propelled both by EU strategies, market forces and a need for quality education among a rapidly more affluent third world student body. Quality assurance has not kept up with the increasing internationalization of higher education, partly because of a lack of accountability. The CDIO initiative constitutes an excellent accountability structure providing quality assurance for engineering education around the world. This paper seeks to show the need for internationalization to be integrated in the accountability structure of CDIO and exemplify it by a self-assessment at Jönköping University – School of Engineering (JTH).

1.1 *Internationalization – a commodity*

The Website of Jönköping University claims boldly the university to be truly international - that they are one of the best in Sweden at international student exchange. Scanning the websites of a number of other universities, similar claims are rampant. Naidoo and Jamieson (1) describe how changes associated with globalization and the knowledge economy have given rise to developments which apply pressure on universities to commodify teaching and learning and “sell” it in the international educational marketplace. Internationalization has become a commodity.

The EU strategies for higher education, like the Bologna Process and the Lisbon Strategy, present an economic rationale to its huge investment in international student mobility like the Erasmus programmes and others. The motive is to bring EU to the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion. As for the Swedish state funded university system, internationalization became obligatory for each university to implement in line with managerialist practices and “massification” of education (2). Exchange students and free movers discovered the exotic tuition free Swedish universities which received increased state fund for each student that passed a course – a truly win win situation.

However, Sweden traces far behind USA, Britain and Australia in capitalizing on the growing market of higher education (3). One reason naturally is the limited number of courses offered in the lingua franca of English as well as the standard of English used in the courses. A survey among free movers, though, reveals another reason. Asked if they would choose a Swedish university if tuition was introduced, a clear majority said no, giving the education not being compatible enough as a reason.

Swedish higher education goes through a paradigm shift during 2011 with the introduction of substantial tuition fees for non-EU students. The affect on enrolment figures at Master programmes has been drastic with a drop of up to 80% at some universities. The enrolment figures the autumn 2011 of international students at the Masters programmes at JTH has not yet been realised, but they are expected to profoundly impact what programmes the university can offer. JTH needs international students to develop, but are now faced with the full impact of competition on the international market of higher education. It is the content, not the wrapping of the parcel in which the customer is interested.

1.2 Learning outcomes

The CDIO initiative provides both standards and syllables with clearly defined learning outcomes as guides towards excellency in engineering education. To assure the same high standard in internationalization, clear learning outcomes are needed. Without them, progress and quality assurance will be hampered. A report (4) from the Swedish Agency for Higher Education (HSV) points out that only a few universities in Sweden have clear policy documents and learning outcomes on internationalization and stipulates that in its recommendation, as does a follow up report 2008 from HSV(5).

JTH adapted a four year vision & strategy plan in 2008, in which a policy document on internationalization is included (6). The ambitious vision states that *“JTH will be at the cutting edge of European development and supply of new technology and knowledge that strengthens the international competitiveness of small and medium size enterprises”*. Other stated objectives are that an international perspective is sought in all activity of the university, that all the educational programmes should be internationally recognized and that the education should prepare for professional life internationally. However, the learning outcomes are mainly dealing with numbers in mobility and courses offered in English.

1.3 International Pedagogy

A quality programme for internationalization does not just contain an effective organisation for marketing and handling the exchange, but also a clear focus on the pedagogy, informal knowledge, intercultural competence and systematic quality assurance. Hellstén and Reid (7), in an excellent

and thorough study on international pedagogy, call for a critical approach to the international aspects of learning and teaching in higher education. While policy aspects of international education have received due interest from the community of scholars, research has not afforded sufficient attention to the applied aspects of internationalization, that is, the teaching and curriculum contexts of this global endeavour (8). Therefore, they emphasize the need for a reconsideration of pedagogies that acknowledge international education through the development of sustainable contemporary academic practices. Hence, it is insufficient for a university claiming to be good at internationalization just to change the language medium to English. The content and learning outcomes of the courses need also to be reworked from an intercultural and international perspective and adapted to the needs of an international student body. The pedagogy needs to be re-conceptualised to include systematic notions of teaching and learning in international contexts and with international students and curricula.

The managerialist practices that has been like an undercurrent in the development of international education tend to assume that educational systems are by an large the same, hence making adaptation of methodology and pedagogy to meet international needs unnecessary. However, a number of the answers in the student surveys in this study claim otherwise, pointing to confusion in not understanding the expectations of the lecturers or how to study for the exam. Therefore, training in international pedagogy and methodology for the academic personnel and curriculum reform would seem a strategic action in raising the international profile of an institution.

1.4 Informal knowledge

How can we ensure policies and programmes that successfully combine socio-cultural objectives with employment and economic growth? The syllabus of CDIO embraces a number of non-formal or informal skills like 2:4 and 3:1-3, as does the EU key competences for life-long learning (9). NESSE, (an EU network of experts in social science of education and training) points out that the European education community must seek new ways to address current social, economic and political realities. What can we do about growing inequalities, or the prejudices that accompany migration and destabilise communities? How can we manage significant demographic changes facing Europe, or ensure that in struggle for public resources the social objectives of education and training are protected? As we are all aware, the kind of answers we give to these decisions affect whether and how education can help realise a socially-just Europe (10).

The European Centre for the Development of Vocational Training (CEDEFOP) has developed guidelines for validating non-formal and informal learning (11). These guidelines can be helpful for universities seeking a focus for their internationalization work. Intercultural competence in line with the Humboldtian ideal is often wrongly assumed to be automatically acquired as soon as a student enters an international exchange programme. If intercultural training is not integrated in the preparation and follow-up as well as during the exchange, precious knowledge on how to become a bridge builder in the increasingly multicultural home environment can easily be missed.

Development and volunteer organisations have generally as praxis to provide thorough preparation, professional supervision and compulsory debriefing for workers sent abroad. The challenges of culture shock, reversed culture shock, managing social interaction in a new cultural context, dealing with ethnocentric attitudes and keeping focused on adapting to the new culture do not come naturally (12). Instead, the natural tendency of an exchange student leaving his or her comfort zone is to avoid emotional challenges and withdraw into comfortable subcultures, resulting in missed opportunities to gain intercultural competence. The objective of cross-cultural volunteer organisations to have a proper mentorship for its workers throughout the mobility is a quality assurance of their international work as well as a professional care for the well-being and personal development of their workers. The exchange students face in many ways the same issues as cross-culture volunteers do. Therefore, internationalization programmes of universities have much to learn from the support structures of experienced volunteer organisations.

1.5 Quality assurance

Extensive work has been done on developing systems of validation of formal and informal knowledge. Little has been done on quality assurance process for the institutions that are expected to provide the learning. The European Qualifications Framework (EQF) seeks to create a

framework as do the HSV reports of Franke (13) and Enquist (14). However, the essence of quality assurance is that it should be done regularly closer to home, linked to the learning outcomes that each institutions supposedly have formulated. Focus should be on the quality of content rather than the quantity of numbers. The following areas need in one way or another to be assessed.

- How the work is organized and followed up?
- What current policy documents are guiding the work?
- How is the curriculum affected by international pedagogy?
- How is the intercultural informal knowledge integrated in the education?
- How is research exchange and international alumni facilitated for?
- What systems of quality assurance are set in place?

Two statistic tools have been provided for universities to assess students sentiments about their exchange; STARS (Study Abroad Report System) and ISB (International Student Barometer). Franke (15) reprimands Swedish universities for not using the tool STARS in their quality assurance. Thus, the valuable experience gained by individual students on international exchange is seldom recognized and used within the organization of the home university. However, complaints have been raised that data from STARS that concerns a specific university is hard to extract and interpret. More importantly, only to a limited extent do the questions address whether the learning outcomes have been reached.

This is also true for ISB, which clearly has a student perspective in its assessment. Though the information is valuable and sheds light on certain areas in need of development, ISB can never substitute a thorough local quality assessment of the international work of a university. As for JTH, the information provided from ISB this year was basically that students were generally pleased with their studies, but would appreciate more help in contacts with local industry.

Gaalen (16) asserts aptly that quality assurance is steadily growing in importance in the field of internationalization. There is currently a widespread belief that internationalization should not be regarded as an end, but rather as a means to improve the quality of education. Many national and institutional policy documents set down quality as one of the major goals of internationalization. At the same time, there is a definite lack of systematic monitoring and evaluation of the impact of internationalization on quality. Hence, there is only limited proof of any direct connection between internationalization and the quality of education.

NUFFIC (Netherlands organisation for international cooperation) provides an excellent matrix or checklist for quality assessment, though 19 pages long, as well as a tool kit on how to do it (17). For further endeavours into quality assessment, the services of NUFFIC would be recommended.

The JTH quality report of 2010 (18) included a section on internationalisation, mainly focusing on numbers regarding mobility. As far as international pedagogy was concerned it emphasized efforts in the area of quality assurance of strategic partner universities, projects with some universities in developing countries and effort integrating an intercultural competence in the educational programmes at home. However, the report falls short of a holistic approach to internationalisation and the report is not well known among the staff in the organisation.

2. METHOD

This self-assessment of the internationalization and mobility conducted within the framework of JTH is based on data collected from ISB, students' essays written within the courses of Multicultural Competence and Intercultural & International Communication, questionnaires and interviews with students, teachers, department heads and exterior stake holders to JTH. The main questions have been:

- What evidence or lack of evidence do you see for JTH being "one of the best in Sweden" on internationalization?
- What suggestions for improvements of do you have for the work of internationalization at JTH?
- What intercultural issues, problems or learning experiences have you encountered during your studies at JTH?

- In what way has JTH helped you deal with those issues?

The data has been collected during the academic year of 2010-2011.

3. RESULT

The result of the study will be presented as summaries of the collected data under headings according to the informants; external surveys like ISB and STARS, students and staff (including teachers, head of departments and external stake holders).

3.1 External surveys.

The external surveys like STARS and ISB show that exchange students at JTH are pleased or very pleased with the work of the international office, their practical arrangements like accommodation, Introduction week and other services and their efforts in arranging cultural events. The quality of teaching also scores well, particularly the graduate school and the prospects a degree from JTH paves the way for. JTH is very eco-friendly. Furthermore, the exchange students are pleased with the opportunity given to make friends with students from their home country and with other international students.

However, JTH scores low in facilitating the entry of the exchange students into the Swedish culture and the interaction with Swedish students or the local population through social or sport events. Particularly low scores are shown in opportunities given to earn money while studying, careers advisory service, counselling service and the availability of bursary or financial support at the same time as the cost of accommodation and living is high.

3.2 Students

Problems dealing with the Swedish time centred (monochronic) culture.

Feeling patronized for not being on time.

I understood that the Swedish preoccupation with time has to do with it being a way to show respect. Of course they get upset if I come late. To me respect is shown through greetings, using titles and in that Swedes are not so good.

Swedes are at times perceived unapproachable and impolite.

Hard to make the Swedes trust you and feel comfortable with you.

The different teaching methods in Sweden emphasizing seminars, group work and group presentations has been difficult.

The cultural course helped understanding cultural differences. We would not have had an as talkative and friendly class without the course. It has helped the multicultural team working.

The cultural course made me feel more comfortable in Sweden

The course helped develop friendships with both Swedes and other students.

I have grown to appreciate the Swedish approach to education using seminars and group work.

The teachers at JTH need intercultural training.

International students have more friends among other international students than among Swedish. Why is that?

I didn't want to end up in a sub-culture of international students so I tried to be flexible and make efforts to get to know Swedes. It is difficult without the language.

Although we have tried to overcome differences, we couldn't get out of our sub-culture groups efficiently. The international and Swedish groups could still not integrate very well.

I have realized that there are cultural differences in the social interaction in Sweden and learnt that many Swedes are not hostile but open to social interaction if they are done on their terms. It has been a journey to learn what those terms are.

I have met problems in cracking the Swedish conversation codes, how to talk and what to talk about.

The intercultural course provided me with lots of cultural understanding on how to interact with people from other countries. It gave me more patience with the others.

I have started to understand my own culture and why I behave the way I do.

As the intercultural course is cross curricula, it gave me an opportunity to meet both students from other programmes and people from the Swedish society that took the course as an elective.

The Swedish teachers are too polite and don't warn students if they are in danger of failing the course.

The English language of some teachers hampers their teaching.

The Swedish educational system provides ultimate comfort for students, they are always given a second or third chance to pass the courses, something that does not exist at my home university.

The best way for JTH to help students into the Swedish culture would be to provide Swedish courses at JTH that do not clash with other courses. The Swedish courses at JIBS are not available for us and the ones at HLK clash with our schedules and are usually too full. The SFI courses given by the municipality of Jönköping is not open for us either.

JTH should provide its engineering students with Swedish courses.

For us master students who stay in Sweden for two years, learning Swedish is very important. Without Swedish, we cannot get even part time jobs here. Knowing Swedish would strengthen our CV. Therefore, JTH should provide Swedish courses for its engineer students.

3.3 Staff

JTH has 78 partner universities with co-operative agreements where exchange of both students and research is sought for.

During the kick off week, international students are introduced to all area of university life.

Courses in intercultural communication are offered to both undergraduate and master students.

The international office is daily available to the international students for support services.

Thorough information and various incentives are used to encourage JTH students to study abroad within the exchange programmes.

JTH has a high number of outbound students (25%), (one outbound to 2 inbound) making many of its Swedish students taking the opportunity to gain international experience.

International students are given opportunity to inform about their home universities and countries.

An International Day for the whole university is arranged with a full day of programme presenting the different cultures represented on campus.

JTH has developed generous rules regarding cross-credit transfer with its partner universities.

JTH prioritizes teaching staff mobility, particularly with the partner universities, thus enhancing the proactive role of the teachers in international exchange.

The council of internationalization has representatives from each department at JTH and governs the strategies a work of all issues regarding internationalization at the university.

Knytpunkten career centre at Jönköping University provides opportunities to meet with future employers and a place where you can ask questions about the labour market.

Non-EU students have had to leave Sweden directly after graduation due to visa regulations without possibility to try the Swedish labour market, a rule that now is being changed.

JTH cooperates with more than 500 companies through the Host Company Project. Students are given the opportunity to combine theory with practice and companies are given valuable ideas. The collaborative work can take many forms — through student projects, research collaborations, courses aimed at specific target groups, participation in networks. However, international students are not part of this project.

The career guidance counsellor is not available for international students

Internship at local companies is not provided for international students.

Through Enterprise Europe Network (LTC) some of JTH's international students have received internship in companies.

JTH does no promotion among its 500 regional host companies of the international network it has of good masters and undergraduate students from all over the world.

The advisory council with representatives from regional enterprises pointed to the need they have of intercultural competence among the graduates of JTH, particularly in the lights of new demands on doing things right on the global market.

The new tuition rules in Sweden demand a more effective marketing strategy, where the needs of international students must get centre stage.

An effective alumni organization needs to be developed.

The important role of the alumni needs to be recognized, both by providing network for career opportunities and further studies, but also recognizing their important role within marketing JTH.

As for outward bound students, a one day session is given on practical advice for their mobility, but no training on intercultural issues, no mentoring during their mobility and no debriefing upon their return.

The individual international exchange experience of outward bound students is seldom recognized and made used of in the organization.

Quality assurance is regular and vital for the development of the work and educational programmes at JTH. CDIO provides the framework for much of the quality assurance. Quality work is performed within the frame of annual activity plans and accounted for in the subsequent annual report.

No quality assurance has yet been conducted of the internationalization work of JTH.

JTH's intranet Ping Pong can easily be used to create a survey based on the local learning outcomes on internationalization.

4. ANALYSIS

Based on the discussion above, the NUFFIC checklist on quality assessment and Campbell's proposal for CDIO Standard 13 (19), a list of evidence of excellence in internationalisation is presented which are used as a benchmark for the performance of JTH on internationalisation.

4.1 Evidence of excellence in Internationalisation

1. The institution has a regularly updated policy document stating aims, strategies and learning outcomes in regards to internationalisation.
0 1 X 2 3
2. The budget for internationalisation corresponds with the ambitions in the policy document.
0 1 2 3 X
3. Quality assurance is regularly applied to assure high standards in internationalisation.
0 1 X 2 3
4. Surveys to assist in the quality assurance are based on the local policy document and prepared for both inbound and outbound students as well as for teaching staff and other stake holders.
0 X 1 2 3
5. The institution actively stimulates its students to complete part of their study programme abroad, striving for a balance between inbound and outbound students.
0 1 2 3 X
6. There is a relative balance between the number of outbound and inbound exchange students.
0 1 2 X 3
7. The institution implements international pedagogy in its educational programmes through curriculum reform and by adapting courses and methodology to international demand.
0 1 2 X 3
8. Training in international pedagogy is provided for the teaching staff.
0 1 X 2 3
9. The communicative ability in English of the teaching staff is high.
0 1 2 X 3
10. The support structure of internationalisation is staffed according to the volume of mobility and ambition of the policy document.
0 1 2 X 3
11. The personnel involved in support and management of internationalization have intercultural experience.
0 1 2 3 X
12. The management council of internationalization has representatives from all sectors of the university assuring a comprehensive implementation of international policy.
0 1 2 X 3
13. Outbound students undergo a training programme in intercultural competence, including preparation, assignments during the mobility and a debriefing on return.
0 X 1 2 3
14. Accommodation for foreign students is arranged in a way that it enhances integration with the domestic students and local community.
0 1 X 2 3
15. Practical information regarding the mobility is presented both orally and in writing in a pedagogically effective way.
0 1 2 X 3

16. Intercultural communication has an integrated part in the educational programmes for both domestic and foreign students.
0 1 2 X 3
17. All educational programmes strive towards developing skills in multi-cultural team process.
0 1 X 2 3
18. Seminars are provided for foreign students on academic writing and other academic peculiarities of the national educational system.
0 X 1 2 3
19. Local language courses synchronized with the schedule of international students are provided from an early stage in the mobility.
0 1 X 2 3
20. The institution has a large network of international partner universities, based on policy and programme compatibility.
0 1 2 3 X
21. A policy based strategic partnership with selected universities is developed, dealing with exchange on undergraduate, graduate, research and faculty level.
0 1 2 X 3
22. The Advisory Board and regional enterprises with international involvement are actively participating in the strategic partnerships.
0 X 1 2 3
23. The institution has a strategic partnership with at least one university in a developing country.
0 1 2 X 3
24. The institution offers a multitude of courses in English to which domestic students are stimulated to enrol.
0 1 2 X 3
25. Internship or work placement in regional companies is available to international Master students.
0 1 X 2 3
26. Links are provided for foreign students to local platforms (sport/social associations etc) where contacts with the local community can be made to enhance acculturation.
0 1 X 2 3
27. The majority of the faculty has international experience or background.
0 1 2 X 3
28. All faculty, staff and students participates in international research projects.
0 1 X 2 3
29. A network is developed for international alumni focusing on competence development and career opportunities.
0 X 1 2 3

4.2 Evidence found wanting

The test shows the result of 43/87 which is a weak 2 where 1-29 = 1, 30-58 = 2 and 59-87 = 3. JTH has some strengths regarding internationalisation namely;

- in the support structures and work of their international office.
- their effort on promoting and sending students abroad to study.
- the wide range of partner universities.
- the training offered at home in intercultural competence.

However, there are a number of areas where there is space for improvement:

- A comprehensive policy document with clear learning outcomes guiding the internationalisation.
- A system of quality assurance including locally produced surveys.
- Training and support of teaching staff in international pedagogy.
- A training programme for the outbound students.
- Facilitating integration in the arrangement of accommodation for foreign students.
- Bridging the gap between procedures and routines of the Swedish educational system and that of the exchange students.
- Starting up tailor made courses in Swedish for both undergraduate and master students.
- Open up the internship programmes and network with host companies (partnerföretag) to foreign students.
- Further develop the strategic partnership with selected universities.
- Involving regional enterprises in the internationalisation work of JTH.
- Develop a holistic network for domestic and international alumni.

CONCLUSION

In ancient Mesopotamia, there was a presumptuous king who thought the world of himself. A writing on the wall disclosed his fate; *you have been weighed on the scales and found wanting* (19). Soon competing kingdoms had overtaken him. JTH has been found wanting, but losing market shares to other universities is unlikely as it is hard to find other universities better in the area of internationalisation.

On an ever increasingly competitive educational market, students will not be gullible to marketing slogans on WebPages, but look to the content of the services. Excellence in internationalisation will enrich the services and strengthen the educational programmes, which in turn will both enhance the growth of the university and its service to a more culturally integrated society. The CDIO with its evolving standards and syllable, thus, continues to be the best quality assurance framework for engineering education worldwide.

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Peer Rating for Feedback in Group Projects

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ABSTRACT

The National Student Survey (NSS) in the UK has since 2005 questioned final year undergraduate students on a broad range of issues relating to their university experience. Across disciplines and universities students have expressed least satisfaction in the areas of assessment and feedback. In response to these results many educational practitioners have reviewed and revised their procedures and the UK Higher Education Academy (HEA) has produced guidelines of best practice to assist academics in improving these specific areas. The Product Design and Development (PDD) degree at Queen's University Belfast is structured with an integrated curriculum with group Design Build Test (DBT) projects as the core of each year of the undergraduate programme. Based on the CDIO syllabus and standards the overall learning outcomes for the programme are defined and developed in a staged manner, guided by Bloom's taxonomy of learning domains.

Feedback in group DBT projects, especially in relation to the development of personal and professional skills, represents a different challenge to that of individual assignment feedback. A review of best practice was carried out to establish techniques which could be applied to the particular context of the PDD degree without modification and also to identify areas where a different approach would need to be applied.

A revised procedure was then developed which utilised the structure of the PDD degree to provide a mechanism for enhanced feedback in group project work, while at the same time increasing student development of self and peer evaluation skills. Key to this improvement was the separation of peer ratings from assessment in the perception of the students and the introduction of more frequent face to face feedback interviews.

This paper details the new procedures developed and additional issues which have been raised and addressed, with reference to the published literature, during 3 years of operation.

KEYWORDS

feedback, peer rating, group projects, skills development.

BACKGROUND

The UK National Student Survey (NSS) is a voluntary, anonymous, online survey of Higher Education students, administered by Ipsos Mori, which has been conducted each year since 2005. It asks final year students to rate their educational experience (on a scale of 1 to 5) on an overall basis and in 21 more specific areas, which are grouped into 6 categories. The stated purposes of the survey are twofold: firstly to publish the statistics (unistats.direct.gov.uk) so that prospective students can be better informed about what and where they might study; and secondly to provide information for educators that could assist them in enhancing the student learning experience. The survey has not been without its

critics and there were some boycotts by students and institutions during the early years. However, almost all Higher Education Institutions (HEIs) in England, Wales and Northern Ireland now have over 50% of their graduating cohorts responding to the survey and national and institutional trends have been identified from several years of statistically significant data. Figures 1 and 2 show data for the Mechanical Engineering and PDD degrees at Queen's University Belfast, which are grouped together in the NSS. Figure 1 shows that the category of 'Assessment and Feedback' is consistently the area with which the students are least satisfied. Figure 2 shows that they find the promptness, clarity and helpfulness of feedback received the most unsatisfactory elements of their entire educational experience. These trends have been consistent over the last 4 years of continuous data. The profile across all Schools in the university is similar and across institutions similar trends have also been identified.

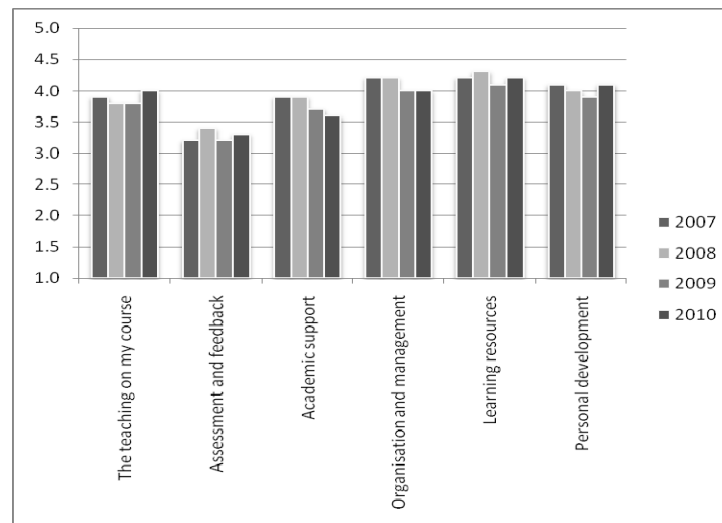


Figure 1. NSS category averages for QUB Mechanical Engineering and Product Design and Development final year students 2007 – 2010

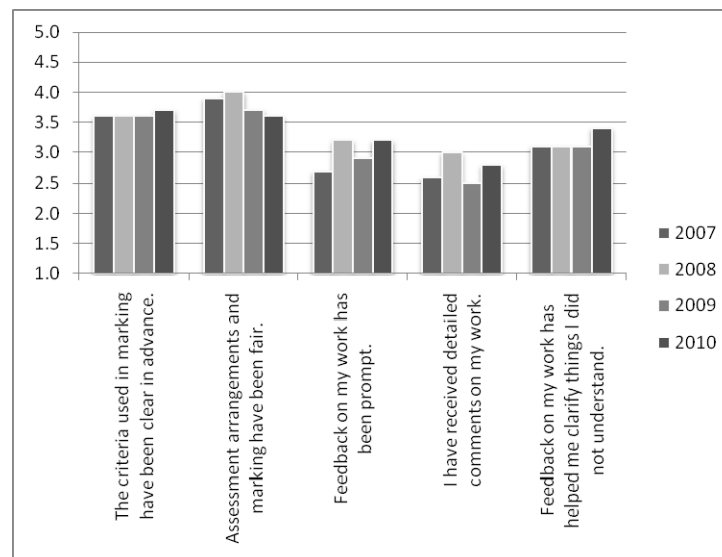


Figure 2. NSS Assessment and Feedback category - question averages for QUB Mechanical Engineering and Product Design and Development final year students 2007 – 2010

In response the Higher Education Academy (HEA) published in 2008 [1] a comprehensive study which looked at longitudinal changes to students' experience of Higher Education in the UK. This included a list of 5 key recommendations and 13 practices which were identified as effective in increasing student satisfaction in the areas of assessment and feedback. Many HEIs subsequently initiated a process of support for academics with particular focus on improving feedback and assessment within their institutions by encouraging the adoption of these best practices.

One of the HEA's key recommendations is that the NSS data is best used to identify areas that require further investigation. Each institution is encouraged to analyse and understand their own context before action to address any deficiencies is taken. An investigation into the feedback procedures in the PDD degree programmes was therefore undertaken by the authors, since the data available from the NSS suggested this was the area in which students were least satisfied.

SOME RELEVANT AND INFLUENTIAL LITERATURE

The DBT projects in the PDD degree require considerable periods of group work in addition to direct contact lectures, tutorials and design review meetings. A review of literature relating to peer assessment was carried out to assess the appropriateness of using this method to assist with the assessment of personal and professional skills such as time management, communication and collaboration in group projects. It was recognised that the students have a different perspective from the tutor on how well these skills are being developed by their peers since they are experiencing the outcomes first hand. Short of being fully embedded in a student group the tutor is restricted to taking snapshots of associated activities on which to base any evaluation of such skills. The approach of using the students involved as a resource to assist with assessment is therefore an attractive option that could be very time efficient.

Many studies have focussed on validating the accuracy of peer assessment when compared with the grades awarded by tutors. These have generally found reliable, accurate and consistent correlations and this has led many tutors to use peer assessment to award or modify marks for individual students in group projects. On the basis of these findings an approach of using peer assessment was adopted on the PDD degree. An earlier study in 1994 at Queen's Belfast by Stefani [2] had found students' assessments of laboratory reports, where the students had drawn up the marking criteria, to be as reliable as their lecturers. In a broad review carried out in 1998 Topping [3] found adequate reliability in the majority of 31 applications of peer assessment but with the caveats that unreliable findings may be less likely to be published and that peer assessment tended to be more reliable than self assessment. Topping also noted that there was considerable variety in how such studies had been carried out making direct comparisons difficult. Others such as Boud [4] have suggested that self and peer assessment is a skill that needs to be nurtured, with guidance from those already skilled in the discipline, and developed over a period of time before students can be considered competent in the practice. Kruger and Dunning [5] noted a significant relationship between a student's competence in a particular domain and the same student's ability to assess their own and their peers' competence in that same domain. The poorest performers were found to be the least accurate assessors and also the most likely to overestimate their own abilities. It was found that in peer assessment situations a clear majority of participants tend to rate their own performance as above average. This could be considered indicative of a general inability to assess accurately, particularly when self assessing, as identified by Falchikov [6] in her review of many such practices. The work of Kruger and Dunning in particular and follow up work by Ehrlinger et al [7] raised issues that caused sufficient concern to prompt a reevaluation of existing procedures.

The conclusion of this reflection was that using peer assessment as a method of generating or moderating grades was potentially less reliable than had first been assumed, particularly when students first use it, due to their inexperience and lack of skill in assessment. Instead it was considered that with only minor modification there existed an opportunity to enhance the educational environment and help students develop the required skills. The procedural changes implemented as a result included discussion of self and peer assessment with students as part of the feedback process. This aimed to provide a structured and supported mechanism for students to develop their own assessment skills in order that they would as Boud [4] contended become more effective continuing learners and practitioners.

PEER RATING FOR FEEDBACK

The PDD degree has been designed using the CDIO integrated curriculum model and has group Design Build and Test (DBT) projects as the core activity of each year of the programme [8]. The majority of modules are continually assessed and the average cohort size is around 25 students. Only 25% of the modules are co-taught with other degree programmes in the School. As shown in Table 1 the stage 1 PDD students undertake 3 short group projects as part of the Introduction to Product Design module and a further 12 week group design project in semester 2. In stage 2 there are 3 x 8 week DBT projects running in series and in stage 3 a 24 week major group project that runs across both semesters of the academic year. This includes the development of a functioning proof of concept prototype and an associated business plan for introduction of the product into the market.

Table 1. Group projects, Supervisors, Peer Rating and Feedback in PDD stages 1, 2 & 3

	Stage1 x 6 week (1) McCartan		Stage1 x 6 week (2) McCartan	Stage1 x 6 week (3) McCartan
	Stage1 x 12 week Hermon (PR1)			
Stage 2 x 8 week (1) (FB1) Hermon (PR2)	Stage 2 x 8 week (2) (FB2) McCartan (PR3)		Stage 2 x 8 week (3) (FB3) Hermon (PR4)	
(FB4)	Stage 3 x 24 week Hermon & McCartan (PR5) (FB5)			(PR6)
week 1	week 12		week 24	

The curriculum structure with a core of DBT group projects coordinated by the same 2 members of academic staff through the first 3 years of the programme provides several opportunities for enhancing feedback. Project groups are constructed at all stages so that by the end of the second year all students within a cohort will have experienced working with all other students in their year group. Table 1 also shows the 6 instances where the students complete a peer rating for feedback spreadsheet (PR1-6) and the 5 instances where face to face meetings take place to discuss the processed results from this process (FB 1-5).

The phrase 'Peer Rating for Feedback' is used instead of peer assessment in order to remove any confusion in the students' minds that their marking is influencing their own grades and the grades of others in their group. Previously it had been presumed that a minority of students had apparently been attempting to distort the process by inflating their own grades. It had not been considered that this effect might be due to their lack of ability to assess. Others who failed to participate fully in group activities tended to score all members very evenly and were reluctant to use the full range of the available scale, in marked contrast to their peers. The current procedures state explicitly that the peer ratings are not used to

adjust grades but rather will primarily be used in the feedback interviews. Carried out on a 1 to 1 basis these interviews concentrate on comparing their rating of the group with the combined totals of all group members, and that of the tutor. The students are told upfront that the interviews will address the accuracy by which they complete the self and peer assessment. Along with the removal of any incentive to inflate their own grades, by separating the process from the assessment, the completion of the peer rating spreadsheet now provides a better mechanism for evaluating student aptitudes in this area. The correct completion of a peer rating spreadsheet is a mandatory requirement for each group project. The interviews are also used to discuss the tutor's assessment of the individual with them, as well as the assessment of them in the context of their group. This provides an opportunity for the student to self evaluate their own ratings when compared to an experienced practitioner. To facilitate this the tutors score each individual on a weekly basis in the same key areas as appear on the peer rating spreadsheets, namely 'technical contributions', 'contribution to deliverables' and 'collaboration', as shown in Table 2. The categories stay the same but the 15 questions differ depending on the content and context of each project.

Table 2. Typical peer rating criteria – 15 questions split into 3 categories

Technical Contributions	Contributions to Deliverables	Collaboration
Ability to apply technical knowledge from other modules (including stages 1 & 2) to project	market research	Effectively takes charge of tasks assigned
Contribute alternative design concepts	Preparation for interim group presentation	Is fair and even in the treatment of ideas/solutions put forward by other group members
Sourcing of relevant technical information	Writing of interim group report	Produces work on time
Demonstrate an ability to apply critical thinking	Construction of concept prototype	Willing to take on tasks
Effectively troubleshoot problems and find answers	Design (sketches, CAD etc.)	Communicates clearly with other members of the team

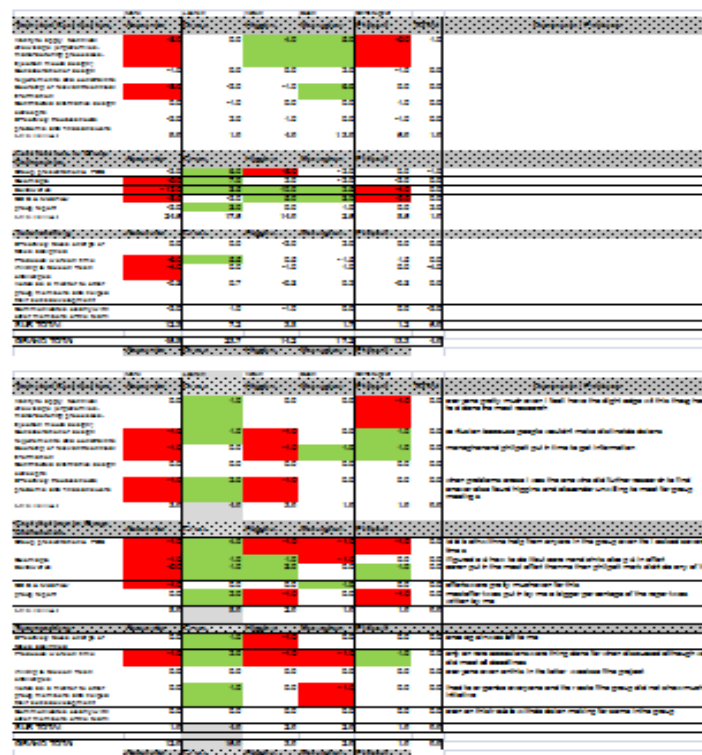


Figure 3. Group total (top) and individual (bottom) peer rating spreadsheets

Figure 3 shows a typical summary sheet produced for an individual interview and tabled for discussion with the student. The top half shows the sum of the peer ratings for the whole group while the bottom half shows the individual's ratings. The columns represent the individuals in a group and there are 15 rows relating to skills, attributes and activities which the student rates on a zero mean basis; the total for each row adding to zero. Individual cells can be scored as a real number between -2 and +2. To assist the discussion, cells which are significantly positive (≥ 0.5 on an individual spreadsheet) are filled green and significantly negative cells are filled red. In this way differences between the individual and group ratings are more easily identified and form the basis for discussion with the student at interview.

Students are required to supply justifying comments for any row with non zero cells. These are printed on the individual bottom half but comments from other members of the group are not disclosed in the top half. The students are made aware before completing the spreadsheet that their comments relating to other group members will remain confidential. This has been done to encourage full disclosure of potentially sensitive interpersonal issues that might otherwise not come to the attention of the supervisors.

EVALUATION

In order to evaluate student opinions of the peer rating for feedback procedures an anonymous questionnaire was carried out during the second semester of the 1011 academic year on the stage 2 and stage 3 PDD cohorts. Table 3 shows the total number of responses for each of 12 questions relating to the procedures adopted, and other related issues which were noted during the literature review; such as student involvement in deciding the rating criteria.

Table 3. Peer Rating for Feedback Questionnaire - Combined Responses from QUB PDD 2010/11 Stages 2 and 3

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Peer rating for feedback is a valuable practice which has helped me reflect on my own performance	14	20	3	2	0
Since the peer rating process does not directly influence the assessment I feel it is a pointless exercise	1	6	8	18	6
I consider the overall group ratings provided an accurate assessment of the relative contributions of the group	1	16	11	9	2
I felt uncomfortable criticising the efforts of my peers	3	10	10	11	5
I would prefer that all comments were made known to the group	2	9	8	13	7
Keeping my comments concealed from the rest of the group allowed me to say what I really felt	4	22	6	5	2
The feedback received on what my peers thought of my performance was useful	7	23	6	2	1
I would like more involvement in deciding the criteria to be included in the peer rating spreadsheets	2	14	20	3	0
I was motivated to work harder knowing that my peers would be rating my contribution	6	23	7	2	1
I was honest in my marking of my peers	22	16	1	0	0
I think other members of my team may have been unfair in their rating of my contribution to the group	3	9	17	10	0
I think that the peer rating marks should be used to adjust group marks for individuals	7	12	11	7	2

Figures 4 and 5 show the results of two of the questions plotted as histograms. These indicate a strong recognition of the benefit of the procedures and also show that the peer feedback regime had a significant motivating effect, despite the fact that there were no marks linked to the process. There was less enthusiasm however for wanting the peer ratings to be used to adjust grades, with the results for the last question in Table 3 showing only moderate agreement. Despite the value placed on the process by 95% of the respondents around 30% thought that the overall ratings were inaccurate and that others may have been unfair in their ratings. It is possible that since the questionnaire was carried out after a number of cycles of feedback interviews had taken place that the students had become conscious of their own failings as assessors and possibly suspected the same shortcomings in others.

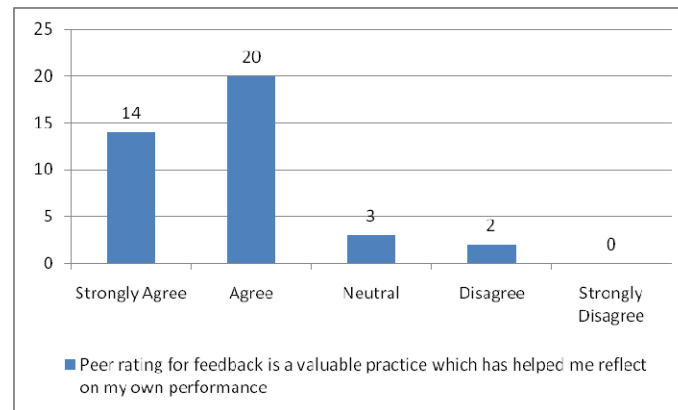


Figure 4. Student opinion of the value of peer rating for feedback

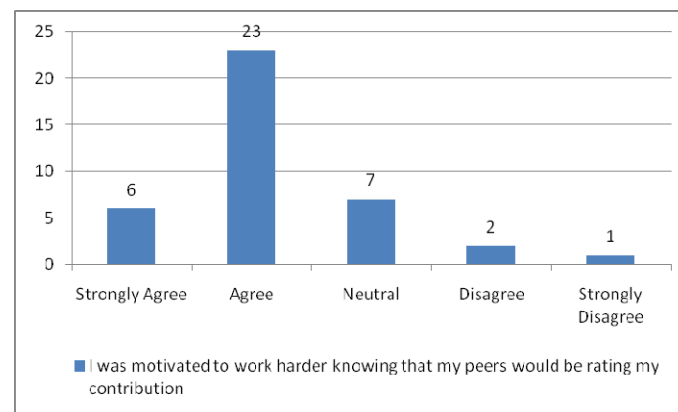


Figure 5. The influence of peer rating for feedback on student motivation

As part of its own internal Quality Assurance procedures QUB operates a system of module review which includes anonymous student questionnaires. The 16 questions cover many of the same topics as the NSS. In particular questions 12 and 15 relate to the usefulness and timely nature of feedback. The questionnaires use the same 5 point scale allowing broad comparison of scores in similar category areas to the NSS. Figure 6 shows the results from the last 3 years for module MEE2026, a stage 2 'Design and Prototyping Projects' module with 3 x 8 week DBT group projects running across 2 semesters, and which operates the peer rating for feedback procedures. It can be seen that Q12 (There was good interaction and feedback between students and lecturer) had an average score of 4.1 and Q15 (The lecturer provided me with helpful and timely feedback on my work) an average of 3.8. These figures are significantly higher than the NSS average of 3.0 calculated for the last 4 years in the same area of feedback (Figure 2).

It must be remembered, however, that the averages have been calculated from data gathered in very different ways, even though the questions are quite similar. The NSS average is for final year students asked to grade their experience of their entire degree and in this case includes data from 2 different degree programmes (Mechanical Engineering & PDD). The online NSS response rate is also typically much lower (reported as 59%) than the module questionnaires which are conducted in class (>90%) and relate to a 1.0 or 2.0 weight module out of a degree programme of 18 (BEng) or 24 (MEng) modules. This demonstrates that while the NSS may indicate general areas with which students are dissatisfied a more detailed analysis down to the module level is required to identify specific reasons for this dissatisfaction. Since the NSS only provides an average for the whole degree it is unclear if single bad experiences or the most recent experiences unduly influence how students rate their degrees.

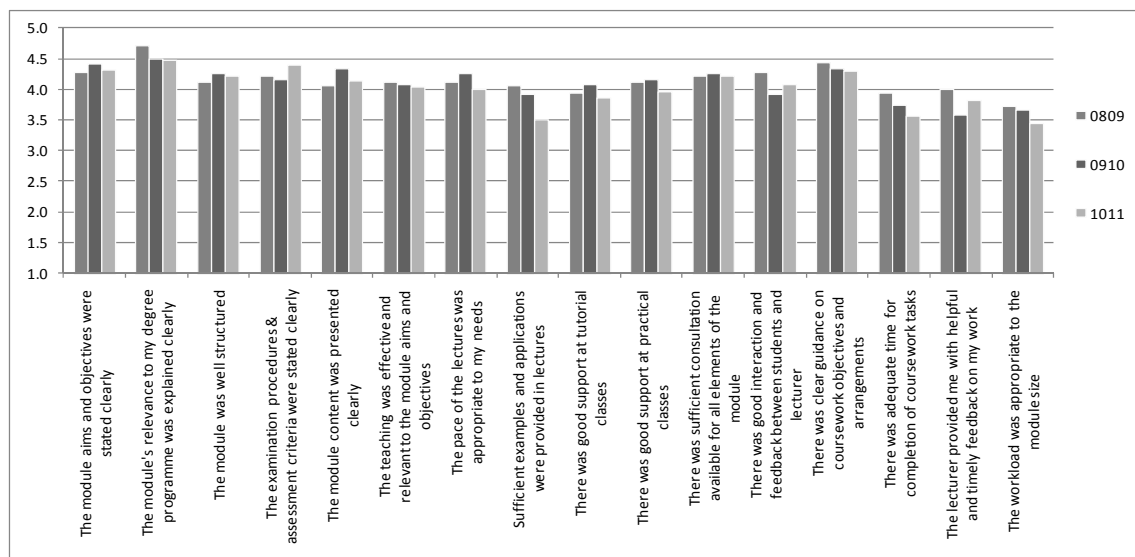


Figure 6. QUB module MEE2026 questionnaire results for 2008/9 – 2010/11

Overall the evaluations carried out so far have shown very favourable responses from the student cohorts and the results from relevant module questionnaires are encouraging. The cohort sizes for the PDD degree are currently relatively small, with an average of 25, and the 2 tutors get to know the individual students very well through supervision of projects in each of the first 3 years of their degree. This clearly improves the quality of feedback that can be provided but raises the issue of scalability of this approach. The authors suggest that by splitting larger cohorts into divisions of up to 30 students it should be possible to construct groups over a similar number of projects in the first 2 years so that each student gains experience of working with most if not all of the other students in their division. If supervisors similarly can be assigned in the same ratio of 2 per division of 30 throughout their first 2 years then the same level of intimacy in the feedback process could be provided.

CONCLUSIONS

- A peer rating for feedback process was developed with minor adjustment to an existing peer assessment regime, primarily by removing the link between peer rating and the assignment of grades.

- By adding a series of formative face to face interviews to discuss the outcomes of the peer rating process an environment was created to help students develop their self and peer assessment skills.
- Student responses showed that they valued the process of face to face feedback interviews which focused on development of self and peer assessment skills through comparison with the assessments of both their peers and tutors.
- Students reported increased motivation from knowing that their peers would be rating their performance, even though it was explicitly stated that these ratings would not be used to alter grades.

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PROBLEM AND PROJECT BASED CURRICULUM VS. CDIO

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ABSTRACT

In engineering education the qualifications and competencies have been determined mainly from the point of view of science and technology. Especially during the 90^{ties} the spectrum of competencies of engineers expanded to concern more social and interpersonal items (teamwork, management), communication (foreign languages, presentation skills), acquisition of knowledge and problem solving: from Theory to Skills. There was a growing gap between the competencies required by the industry and produced by the education system. Traditional engineering curriculum cannot properly face this challenge: there was a need for a fundamental update of the curriculums of engineering programs.

To change the strategy of curriculum totally will start a massive change process, which will cover the whole organisation. All changes create instability to the organisation: the sense of insecurity, incompetence and lack of professionalism. Therefore change management is essential to ensure the continuation of the process. In every change process you need a proper strategy as a backbone of your development process. As a CDIO Collaborator we changed our pedagogical strategy from Problem and Project Learning to CDIO. This means that Problem and Project Learning now has a "tool" status: they are tools for the implementing process.

The Curriculum should be seen as a complete plan, how the learning and teaching are implemented and organized in the program, not just a list of contents. Our present curriculum is based on a hybrid model of Problem Based Learning (PBL) and Project Learning. During the 1st and 2nd study year the basic knowledge and skills are studied mainly with PBL and Project Learning. The focus is on the development of study and process skills. The basic technology of Mechatronics is also learned. In the 3rd and 4th study year the students will work in demanding projects with companies (real life cases). The professional core studies have been integrated in three categories: Automatic Systems, Mechanical Systems and Production Technology. In every study year students will conduct a whole planning and implementation process: from an automatic device (1st year) to whole systems.

In this paper we will discuss how Problem Based and Project Based Learning are related to CDIO and compare PBL and Project Learning to CDIO (key elements, focus, outcomes). We also compare our present curriculum to the 12 CDIO Standards and analyse how they match. How many of the standards are fulfilled from our perspective? As an end result we produce a collection of evidence as a part of that survey and a list of tasks which we have to execute to be considered a CDIO Engineering Program.

KEYWORDS

mechatronics, PBL, Project Learning, curriculum, CDIO Standards

INTRODUCTION

In her article Mélanie L. Sisley refers to many researchers, who state that technological changes have major effects in our minds. High technology is altering our neural pathways faster than ever. Facebook, Youtube, Blogsites and other social medias are forming the personality of our students. This will have significant effects on learning styles and strategies as well. For example young students have learned the way to process data in parallel. They have many parallel mental processes going on simultaneously (“multitasking and partial attention”) [1].

On the other hand, I myself and my colleagues learned to use Internet in the 90^{ties} as clumsy freshmen in the “Electronical World”, which has been changing rapidly ever since. The average age of lecturers in our faculty is nearly fifty years. Our learning styles and strategies were developed during the “Television Era”. We have learned a “one task at a time” strategy: we will be stressed trying to do many tasks simultaneously. Our data processing is “serial”.

In the long run it would be vital for universities and other educational organisations to fill this gap between learning strategies of the teaching staff (professors, lecturers and instructors) and the students. We should also meet the challenges of “new” qualifications for engineers coming from the work life.

With active learning strategies (CDIO, Problem Based Learning, Project Learning) and methods we should update engineering curriculums to face the challenges of the future. Lahti University of Applied Sciences (LUAS) was approved as a CDIO collaborator in November 2010. Just before that we made a faculty level decision to use CDIO as the main pedagogical strategy in the Faculty of Technology. There have been systematic curriculum development projects since the beginning of 90^{ties}. The milestones of that process are listed below.

- Project Learning partially started in 1990 (projects in courses)
- Content update in 1995 (mechanical vs. automation 50/50)
- PBL started partially in 2000
- First Problem and Project Based Curriculum (Engineering) in Finland in 2003
- International PBL Conference in Lahti (with University of Tampere) in 2005 (<http://www.lamk.fi/pblconference>).
- Project Learning as a pedagogical strategy at Faculty of Technology in 2008
- National Project of Engineering Education INSSI in 2008-2011
- First contacts to CDIO (Turku) in 2008
- First faculty level project based curriculums launched in 2009
- Faculty decision to join in CDIO in 2009
- CDIO Fall Meeting in Turku in 2009
- Degree Programmes reduced to four: Environmental, Information, Material and Mechanical in 2010-11
- 6th International CDIO Conference in Montreal in 2010
- PBL triggers will be derived from the projects in 2010-11
- CleanTech-project started in 2010
- CDIO as a pedagogical strategy at Faculty of Technology in 2010
- Project of Engineering Education INSSI II in 2011-2013

PRESENT CURRICULUM IN MECHATRONICS

The first version of our PBL curriculum was completed in February 2003 and it is developing continuously. In September 2003 new students put the curriculum in practice and the results were encouraging. In our curriculum we point out the differences of the planning and implementing processes. This also concerns the developing process of PBL curriculum. On paper everything looks great, but in the implementation process the Quality and Change Management will produce a massive number of problems to solve.

The knowledge is contextualized: we should emphasize the knowledge, that is relevant to the engineer's every-day life. The learning is based on the experimental learning (system) and constructivistic approach (students). At the curriculum level the experimental learning model can be argued by pointing out the Praxis: skills should have the same weight as theoretical studies. The constructivistic learning strategy leads us to build up a genuine student-centred learning environment [2].

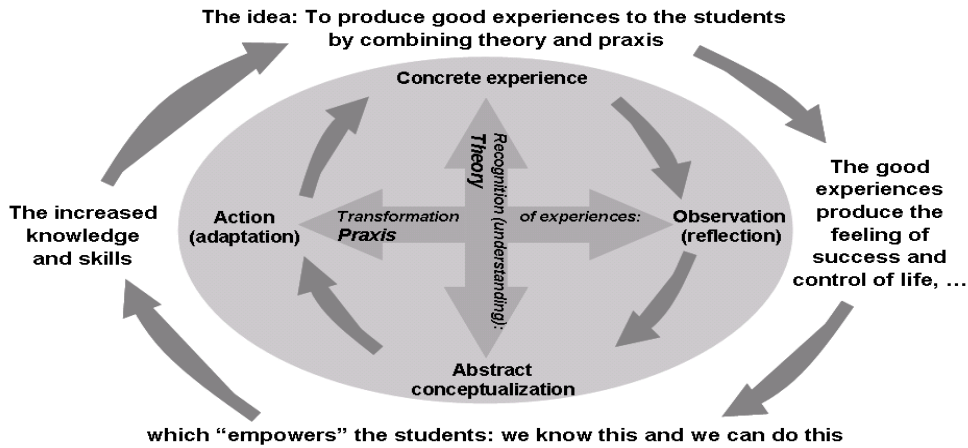


Figure 1: The Experiential Learning (Kolb) and Mechatronics

The starting point to our curriculum development work is Kolb's Cycle: the model of the Experiential Learning by David Kolb (fig. 1). The experiential learning model by Kolb has four phases: a) experience, b) observation (reflection), c) conceptualization and d) action. This is described in the inner circle of Figure 1. The action-observation pair forms the transformation of the experiences axis, which is very strongly related to the Praxis. On the other hand the experiences-conceptualization pair states for the recognition (or understanding) axis, which is based on the Theory [3].

The outer circle of Figure 1 shows how we have adapted this model. By combining Theory and Praxis in every case or problem the students can apply learned theory immediately (not after two years of studies). The structure of the curriculum is presented in Figure 2.

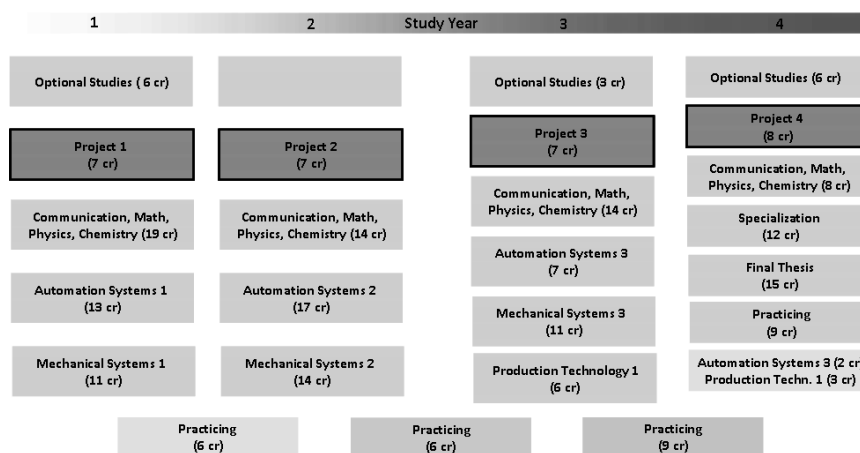


Figure 2: The structure of the curriculum

Mechanics can be described as "the decathlon of Engineering". System thinking is one core concept in our curriculum: the students should learn that the systems in mechatronics form an integrated whole rather than a massive body of components.

Most of the engineers in mechatronics in Finland plan and implement projects. In the Lahti region many companies export over 80% of their production. That is why the engineers should learn how to run international projects. This planning and implementation process of “real projects” was a model for us: every study year we complete one. This project model adopted from the companies was modified in pedagogical form: “Pedagogical Engineering”.

The title for the first year project is “an Automatic Device”: the students should be able to plan and construct such a device as a team. During the second year they are expected to finish a project, which generates accurate movements (positioning, CNC). During later phases of studies the students will make “real” company projects. This preconceives that students are capable to accumulate knowledge in layers.

The assessment and evaluation guides the students` work more than we think: what you order, is what you get. The wider spectrum of qualifications postulates a wider spectrum of means in assessment and evaluation. The assessment system in our curriculum has two major components: a) the process assessment (summative assessment) and b) the result evaluation (formative evaluation), which are equally weighted [4]. The process assessment is based on:

- the students` self-assessment (form) and feedback discussions
- the peer assessment among the study groups and feedback discussions
- the assessment of the tutorial performance by the tutor
- personal and group interviews twice a year.

The components of the result evaluation are tests, skill tests and reports.

The last but not the least feature is the classification of objectives. There are general objectives for the whole education (four years), and process and content objectives for every study year. Every study module has objectives of its own and so does every case or problem.

The documents of the curriculum are a) curriculum description in the student’s guide book (general description of the studies and study modules), b) study module manuals (tutor and student versions) and c) cases (case description, implementation plan and the guide for reporting, assessment and evaluation).

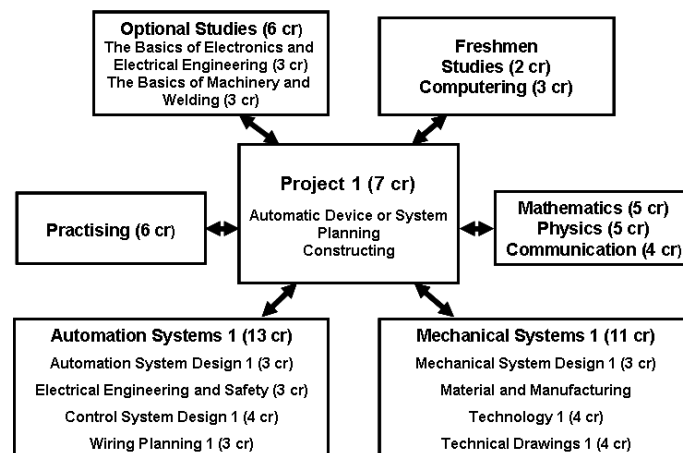


Figure 3: Projects in Focus

Figure 3 shows how the first year studies are implemented. Almost all courses are linked to the project. Courses of Automation and Mechanical Systems are studied with PBL cases, which are derived from the project. For example the case in Control System Design is to produce a PLC program to a system which is very similar to the system in the project. The contents of courses are driven directly from the project. Items which are not relevant to the project have been dropped out. The qualifications of a mechatronics engineer have also been reflected: the contents of the courses must have a direct connection to an engineer’s daily work. In this way we have managed

to provide “on demand” course contents, which focus only on the items necessary to run the project.

COMPARISON OF LEARNING STRATEGIES: PBL, PROJECT LEARNING AND CDIO

The World is full of acronyms, which stand for a large variety of pedagogical strategies and methods: PBL, PPBL, IL, RBL, TPL. The hybrid model of Problem and Project Based Learning is perhaps the most suitable model for engineering education [5]. How are these learning tools connected with CDIO? Which are the key elements, focus and outcome of these methods? Table 1 shows the characteristics of CDIO related to PBL and Project Learning.

The key elements of CDIO are the 12 Standards and the CDIO Syllabus. They form an international framework and overall development strategy. From our perspective the advantages of joining CDIO are international context, benchmarking and continuous program development. In CDIO we can learn from other universities and exchange experiences. CDIO is also a part of our Quality Assurance.

Table 1

Comparison of Problem Based Learning, Project Based Learning and CDIO

	Key Element	Focus	Outcome
CDIO	Standards Syllabus	Overall Development Strategy	International Context Benchmarking Continuous Program Development
Problem Based Learning	Tutorials Cases/Triggers	Learning Process Assessment	Learning Skills Teamwork Self and Peer Assessment Skills
Project Based Learning	Real Life Projects	End Results Evaluation	Planning Skills Construction Skills Product Development Teamwork Project Management Motivation

Problem Based Learning is used as a study model in the courses of Automation and Mechanical Systems. The courses are wrapped around PBL cases and triggers. The students work in small groups (6-9 students) following the study cycle shown in Figure 4. Every student group has been appointed a tutor from the teaching staff, who will guide the group in weekly tutorials and during the study process. The tutor and student group form a team, where both PBL cases and projects are performed. This cycle study model was originally developed in the University of Linköping Sweden and completed by Esa and Sari Poikela with the aspects of assessment [6].

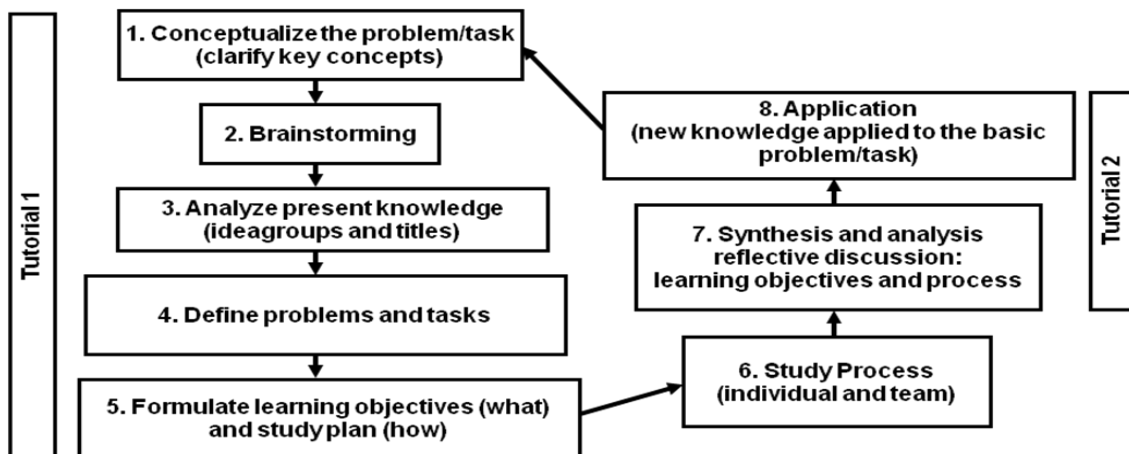


Figure 4: PBL Study Cycle

The cases and triggers are presented in the opening tutorial. The outcome the tutorial is learning objectives for the student group. The idea is that when producing the learning objectives of their own, the students will be better motivated. The ownership of learning is transferred from the tutors to the students. They also learn problem solving methods like Brainstorming. After tutorial follows Study Process. It contains individual and team learning, lectures, exercises and skill training. The final phase is the closing tutorial. There the case or trigger will be closed with reflective discussion. The newly formed knowledge is applied to the original case or trigger: have the learning objectives been met, problem solved and study plan followed? In every phase evaluation and assessment are included. This cycle takes at minimum four weeks and maximum four months.

Henk Schmidt and Jos Moust have analyzed PBL from following aspects:

1. Cognitive processes in tutorial discussions and their impacts on learning results
2. Impacts on motivation
3. Tutor's impact on learning

In this study the researchers suggest that cases or triggers (learning tasks) have a more significant impact on learning than expected. The quality of learning tasks is even more important than the competence of the tutor [7]. Henk Schmidt and Wim Gijsselaers developed the theoretical model of PBL. The model has three groups of factors: input, process and output factors as seen in Figure 5 [8].

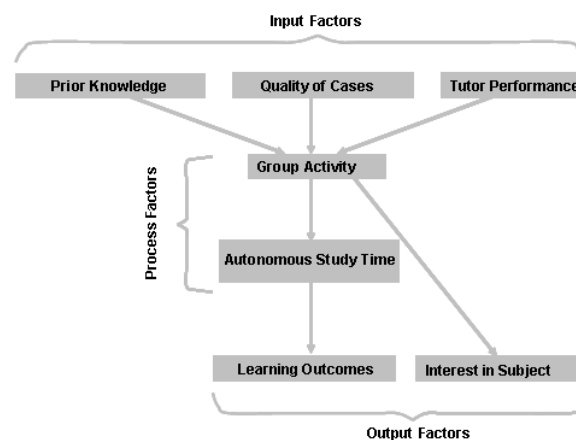


Figure 5: PBL model by Schmidt and Gijsselaers

Input factors refer to the character of students, tutor behaviour and the quality of study materials. Process factors contain the study skills of students (especially during the autonomous study time), study hours and the guiding process. In output factors you can find learning outcomes and the

interest in the subject, which has an outstanding impact on motivation. The researches completed their model by calculating the correlation between the factors (fig. 6). Correlation varies between -100...+100. The larger number means stronger correlation.

The strongest correlation is between the group activity and the interest in the subject (57). The quality of triggers activates prior knowledge and has a major impact on group activity. Tutor competence has lower correlation than the quality of triggers. As a conclusion, in the PBL study process tutor does not have to be a “Superman or –woman” but the triggers have to be carefully planned. The main factors in tutor competence are social and cognitive congruence and use of professionalism.

With the Problem Based Learning study process it is difficult to solve complicated real-life engineering problems. Project Learning model would do better. In Project Learning the end results are emphasized and the study process is more straightforward than in the Problem Based Learning. With projects you learn practical planning and construction skills. Every project is also a product development process. If students run the project in the same small group as PBL cases, they can utilize PBL study skills to recognize problems and solve them in their projects as well.

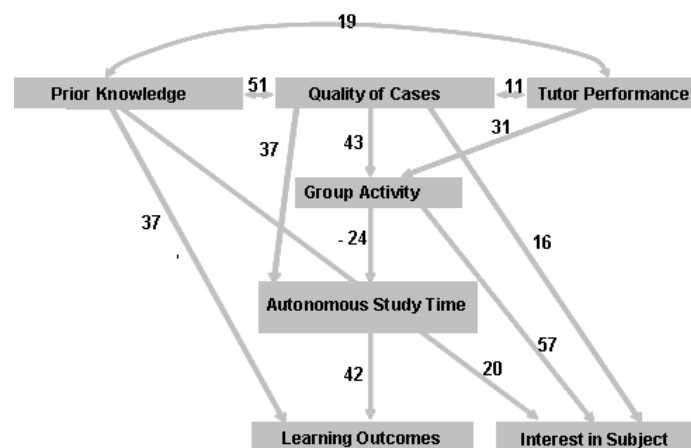


Figure 6: PBL Model with correlations

The results of the PBL Model can be generalized to concern also the projects: especially the first two projects must be carefully planned. They should be complicated enough to provide intellectual challenges for the students. On the other hand the knowledge and skills learned during the first study year should be adequate to finish the project. They should also have a strong connection to work life (realistic projects). From the project management point of view these projects are demanding for the tutors. When the students are using machines and making electrical installations, safety must be secured and they should be supervised and instructed. This requires planning and designing skills from the tutors.

Here are some examples of the projects implemented in 2009-2010:

- Project 1: "Poor Man`s Segway"
- Project 2: Automatic cable measuring and cutting device
- Projects 3 and 4 are company projects: Testing device for surface switches, RFID (Radio Frequency Identification) system in production, Machine vision system for food industry

THE 12 CDIO STANDARDS VS. PRESENT CURRICULUM

The 12 CDIO Standards were updated in December 2010. In this revised edition each standard is disassembled in three sections: description, rationale and evidence. The description explains the meaning of the standard, the rationale highlights reasons for setting the standard, and evidence gives examples of documentation and events that demonstrate compliance with the standard [9]. We have reflected the standards through our program development in mechatronics. The results are shown in Table 2.

Table 2
The 12 CDIO Standards and Program Evaluation

CDIO Standard	Condition	Evidence
1. CDIO as Context	Mission statement done Deployment: conversion PBL to CDIO under construction	Faculty Decision OK Approval as CDIO Collaborator 11/2010
2. CDIO Syllabus Outcomes	Done	Learning outcomes in curriculum validated by stakeholders
3. Integrated Curriculum	Mainly done Mapping under construction	Curriculum
4. Introduction to Engineering	Done	Project 1, Freshmen Studies, Curriculum, choices of elective courses
5. Design-build Experiences	Done	Projects
6. CDIO Workspaces	Mainly done Workshops should be modernized	Laptops, workshops, labs, Moodle, teamwork rooms
7. Integrated Learning Experiences	Done	PBL, Projects, Company projects and seminars, final thesis
8. Active Learning	Mainly done High level of achievement of all CDIO learning outcomes?	PBL, Projects, Student feedback
9. Enhancement of Faculty CDIO Skills	Mainly done Hiring policies should be improved	CDIO as Pedagogical Strategy, Pedagogical Training Program
10. Enhancement Faculty Teaching Skills	Done	Pedagogical Training Program, National Evaluation Meters, Follow-up of study progress and backup, guidance
11. CDIO Skills Assessment	Done	Evaluation and Assessment System, Projects, PBL
12. CDIO Program Evaluation	Mainly done Documentation should be improved	Student Feedback System, Company Projects

Since we have used active learning methods in the degree program of mechatronics for over 20 years, it is obvious that our learning objectives and outcomes match the CDIO Standards. Our main pedagogical strategy has been PBL and Project Learning. Therefore our students and staff are familiar with the PBL, but not yet so much with CDIO. That will be changed in the near future. Mapping of learning objectives and outcomes has to be done during the next academic year (major update in curriculums). We have satisfactory CDIO Workplaces, but they should be modernized. How to measure high level of achievement of all CDIO learning standards? In the future we will also pay more attention to the recruiting process and use CDIO skills as one qualification. In internal program evaluation we should improve the documentation. A more detailed external evaluation takes place every 2-3 years.

CONCLUSION

The hybrid model combining Problem and Project Based Learning provide a firm basis for the curriculum development of a CDIO Engineering Program. The learning outcomes in Problem and Project Based Learning will match those of the CDIO Syllabus. Problem Based Learning is effective in "learning to learn": reflective attitude, assessment and teamwork skills. Project Based Learning could be adopted when the raw end results should be produced: when evaluation, problem solving, scheduling, project management and performance of work are required.

From our perspective, the curriculum of Mechatronics will meet six of the 12 CDIO Standards. The rest of them will be passed in two years (2013). A detailed mapping of learning outcomes between the CDIO Syllabus and the present curriculum is the main task to do.

The key elements of CDIO are the 12 standards and the CDIO Syllabus. These documents will answer the question “what” you should do to develop a CDIO Program Curriculum. To get the answer to “how” to do it, the tools have to be chosen for curriculum reform. With these tools the “educational system” can be planned and implemented. The Learning takes place, when the “system” makes the persons (students, staff and stakeholders) work as a team together to create new knowledge and skills.

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North American Aerospace Project - Adaptable Design/Build Projects for Aerospace Education

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ABSTRACT

The North American Aerospace Project (NAAP) is a NASA/industry sponsored effort to accelerate penetration of the project-based educational concept of “Conceiving, Designing, Implementing, and Operating” (CDIO) into US Aerospace Engineering programs. NAAP is developing innovative educational approaches, tools, methods and concepts specialized for the education of the future aerospace engineers. Several projects have been made available in a standardized template format. The template is designed to help an interested faculty member to quickly adopt a project and introduce it in a class.

KEYWORDS

Education, workforce, projects, template

I. Introduction: A project relevant to industry needs

Aerospace generally, and aeronautics particularly, is a key sector of the US economy, contributing significantly to the gross domestic product, positive balance of trade, and national security. Yet the sector is facing a systemic challenge – maintaining a world-class workforce. Over the next decade, the demographics of the sector suggest that there will be a significant shortfall in technically competent engineers and other technical specialists necessary to keep this sector healthy, and preserve the nation’s aeronautics core competencies.

From a national policy perspective, this need has been clearly recognized. The *National Aeronautics R&D Policy* instructs that “executive departments and agencies with responsibility for aeronautics-related activities should continue to invest in educational development of the future aeronautics workforce...” The *NASA Strategy Plan of 2006* references the need for NASA’s own Strategic Management of Human Capital, and in the section on Strategic Communications: Education Initiatives reinforces NASA’s responsibility to “strengthen NASA and the nation’s future workforce” and to “Attract and retain students in STEM Disciplines”. The NASA goals include taking “responsibility for the intellectual stewardship of the core competencies of aeronautics” which certainly includes their retention by the workforce. The importance of STEM workforce is paramount to other organizations as well, including the NAE, the AIAA and the AIA.¹ In 2005, bipartisan requests from the US House of representatives and the US Senate prompted the National Academy of Sciences to conduct a study, known as the “Gathering Storm” report, of America’s competitiveness in the evolving global market. The study led to the American COMPETES Act. The revised report² of 2010 concludes that the gathering storm has reached “Category 5”. In their overall assessment the committee concludes that

“overall the United States long-term competitiveness outlook has further deteriorated” since 2005, and that “America’s younger generation is less well-educated than its parents.”

Our consortium has proposed a solution that is designed to have widespread systemic influence on the university preparation of the aeronautics workforce. The program seeks to strengthen US university programs that prepare aeronautical engineers, and to develop and disseminate curricular materials and methods in a form that is easily transferred to and adopted by others, to use in reforming and strengthen their programs. Our architecture will furthermore encourage participation from the extended community of aerospace programs, adding their innovations to a readily accessible library.

II. Impacting the knowledge and skills of graduates

Over the past eight years, a growing number of international engineering schools have formed a collaboration to develop a new vision of engineering education called the CDIO Approach (www.cdio.org).³ CDIO is designed to deliver the knowledge and skills needed by industry. It provides an education stressing engineering fundamentals, set in the context of the **C**onceiving, **D**esigning, **I**mplementing, and **O**perating process.

The CDIO approach identifies and implements 12 Standards of Effective Practice. Critical to them is the extensive use of Project-Based Learning (called here PjBL to distinguish it from the more general Problem Based Learning). A key innovation is the integrated use of PjBL in both the earlier and later years of the undergraduate education. Such use of PjBL has been shown to increase the acquisition of deeper knowledge and develop in students desired product and team skills.⁴⁵ Such active learning approaches attract and retain more students in engineering. Interestingly, it has been demonstrated that exposure to Project-Based Learning in the first and second year preferentially retains women (and potentially minorities) in engineering,⁶ and exposure in the junior and senior years influences the career choices of students away from non-engineering paths, back to careers in engineering.

In the ongoing effort, we are developing modularized curricular materials around aerospace PjBL.

III. Sustaining the program

In order to address the aerospace workforce agenda over the next decade, innovations must be sustainable - in terms of faculty members’ time, skills and interests, the financial resources, and the effort required to identify appropriate industrial projects. The first element of sustainability is to directly produce project-based materials that are easily available and ready to use. We are developing and refining modules for project-based learning of aeronautical knowledge and skills that are well described, and available in a standardized format on the Web. A project module includes instructor notes, activities, material descriptions, student activities and learning assessment tools. We are deploying a Web-based mechanism by which the aeronautics industry becomes involved in defining the projects for a given school year, without having to interact individually with each of the hundreds of programs across the nation. Finally, we are addressing the most fundamental issue, the skills of the faculty in delivering project-based learning. A Faculty Development Workshop has already been created and already delivered at our participating institutions.

IV. A broad-based approach with national impact

The project is led by three core universities: MIT, the US Naval Academy, and the University of Colorado, Boulder. But, we are already engaged in the North American CDIO region with three

other universities, and recently been joined by several others. About 10 major aeronautics programs have expressed strong interest, motivated significantly by strong industry endorsements. We have an inclusive approach, and invite all to participate. As described below, we have entered into partnership with many of the leading US-based aerospace companies, and will work through them to engage their “feeder” programs around the nation. Our hope is that in two to three years, 20 to 30 of the major programs around the nation will be involved in the CDIO in Aerospace Education network. We view this goal as achievable, with over forty universities and 70 programs are now involved in the international CDIO Collaborative spanning all fields of engineering.

V. Technical Approach - Forming an alliance

The project has assembled a national team of educational scholars, developers, deliverers and customers. We have formed an integrated project team, built around a core group of the three key North American CDIO programs in aerospace: MIT, the US Naval Academy, and the University of Colorado, Boulder. This core group was joined by four other existing CDIO programs in the US and Canada: Arizona State University, Daniel Webster College, California State University at Northridge, and École Polytechnique de Montréal. Daniel Webster College students were partnering in the Helios project at the University of Colorado, which is described below.

We have approached the Boeing Company, General Electric Aviation, Lockheed Martin, Northrop-Grumman, Orbital Sciences, and Raytheon to form an industry-university steering group for the program. These industries are contributing direction, participation in project learning, and supplemental funding.

VI. Developing aeronautical project-based learning and assessment materials

The core of the technical effort is the development of design-implement-operate laboratories and project-based experiences. We are developing a set of at least six learning experiences for the first and second year of aeronautical instruction, and about six third/fourth year learning experiences. Working in close coordination, and with the guidance of the industry-university steering group, each of the three core universities has developed one experience at the freshman/ sophomore, and one at the junior/senior year level this past year, and will develop a like number in the coming year. First results were reported at the AIAA Annual Meeting in January of 2010⁷.

A. First and second year project-based experiences

It is important to begin the education of engineering students with an authentic experience in engineering, often delivered through a project-based subject in the first or second year. We are developing two types’ experiences. In one model, the laboratory or project-based experience is a simple but rather complete aeronautical vehicle, at the scope that can be successfully developed by students, but with an interdisciplinary perspective. In the second freshman/sophomore model, the laboratory project will be based on the design and development of an important aeronautical subsystem.

B. Third and fourth year project-based experiences

We are developing third and fourth year experiences of two types. In one, the entire class work as one team in the execution of the project. In the second, smaller groups work in teams of 6-10 on the project. In most cases, the projects have a real customer, and deliverable “flying” article. Projects are interdisciplinary spanning modern aerospace disciplines (aeronautics, propulsion and structures, avionics, software, control and autonomy). The projects build

awareness of other issues, including financial, regulatory, environmental and public policy, although this broader interdisciplinary scope may not be a primary focus of every project.

The underlying innovation in these projects is the incorporation into the mainstream curriculum of the design, building and testing of realistic, in fact in some cases real, aerospace vehicles and systems.

Upper-class projects are being readied for publication and will be available in 2011. The project teams will then move to documenting additional projects by the summer of 2011.

VII. Develop dissemination and faculty development support materials

Two important barriers to adoption of innovative instructional approaches such as project-based learning are the lack of well-developed examples from which individual faculty can draw, and the lack of confidence and competence of university instructors in such approaches.⁸ We develop a comprehensive approach to dissemination of our results, which include making the curricular materials that we develop openly available on the web, and creating Faculty Development Workshops and Master Teacher Seminars. These workshops were publicly offered at the 2010 national meetings of both the AIAA and ASEE.

VIII. Pedagogic Foundation

Contextual learning is a proven concept that incorporates much of the most recent research in cognitive science.^{9,10,11} According to contextual learning theory, learning occurs when students process new knowledge in such a way that it makes sense to them in their own frames of reference. This approach to learning and teaching assumes that the mind naturally seeks meaning in context, that is, in relation to the person's current environment, and that it does so by searching for relationships that make sense and appear useful.¹² A contextual learning approach assists students in learning how to monitor their own learning so that they can become self-regulated learners.¹³

IX. Capabilities and experience of the team

The three lead institutions, MIT, USNA and CU Boulder, have each undergone significant curricular transformation as a consequence of adopting CDIO, and are viewed as important contributors to educational reform. The Department of Aeronautics and Astronautics at MIT developed the CDIO Syllabus and revised its undergraduate program in the context of CDIO. The Naval Academy has been a CDIO collaborator since 2002, contributing a strong emphasis on engineering operations, particularly manned and unmanned flight test. The Aerospace Engineering Sciences Department at the University of Colorado has redesigned the undergraduate curriculum to include laboratory experiments and design projects according to the CDIO Syllabus in 2000. In the sophomore and junior years the fundamentals are taught enhanced by experimental labs and small design projects. All courses in these two academic years make extensive use of the Integrated Teaching and Learning Laboratory. Senior design projects teach standard professional aerospace systems engineering practices, elements of conceptual and detail design, elements of fabrication, integration, verification and test.

Collectively, the three universities have already been working together for three years through their close working relation in the North American CDIO region. To date, the collaborative has influenced over 70 university engineering department programs worldwide, which graduate close to 10,000 engineering students annually.

X. Project Examples

A. *First and second year project-based experiences*

It is important to begin the education of engineering students with an authentic experience in engineering, often delivered through a project-based subject in the first or second year. We are developing two types experiences. In one model, the laboratory or project-based experience is a simple but rather complete aeronautical vehicle, at the scope that can be successfully developed by students, but with an interdisciplinary perspective. Our first selection of these projects included:

- The development of an RC lighter than air vehicle, capable of being flown under radio control over a closed course, teaching equilibrium and simple flight mechanics
- The design and testing of water rockets, a deceptively complex problem providing an interesting design optimization challenge, spanning gas dynamics, rocket dynamics, stability, aerodynamics, and launch system integration.
- The redesign and refinement of a simple RC electric aircraft.

In the second freshman/sophomore model, the laboratory project was based on the design and development of an important aeronautical subsystem. These include:

- The development of a flight control system for a 3 DOF helicopter simulation, including characterization of a helicopter's system dynamics and design of a simple feedback control
- Fabrication/test of a composite material truss member - a unidirectional glass fiber reinforced epoxy matrix strut that can sustain a theoretical load of 3500 lbs without failing
- Design and modeling of a high-altitude zero-pressure balloon carrying a payload with minimal altitude variation caused by thermal heating and cooling.
- Wind tunnel calibration and low-speed aerodynamics of the Lockheed Martin F-16

As an example of the approach we have used in these first/second year projects, we will describe one involving the redesign of a simple RC electric aircraft, currently employed at both MIT and USNA. This project is a major component of both programs, and consists of a series of labs and design exercises which culminate in a flight competition. The objectives of the project are to provide: a framework for the smaller course labs (wind tunnel tests, beam bending tests); a theoretical and hands-on application of the taught disciplines; an introduction to engineering tradeoffs and design optimization; an introduction to aeronautical terminology and practice; and to generate enthusiasm and camaraderie in our students.

Each student team designs, builds, and competes in a fly-off an electric RC airplane optimized for an assigned objective, such as maximizing a weighted combination of endurance, maximum speed and payload. The rules are carefully formulated to give each team sufficient design freedom to explore various design options, for example: wing aspect ratio, taper, and twist; airfoil camber and thickness; tail volumes; and configuration (tractor vs. pusher). The pedagogic approach is to teach design by redesign. Students start with an existing kit plane, and analyze and improve one or two aspects of it to increase the performance against the stated objectives. The rules emphasize operations, and are made sufficiently constraining to put all teams on roughly equal footing, and to simplify the structure to make the overall aero/structural optimization quantitatively tractable rules. A planned innovation in this project is to include a more detailed and realistic structural design, perhaps employing composite materials.

A second example involves the design and test of a spacecraft thermal system. Students are formed into teams of 3-4 students to evaluate the design of a radiator for a satellite. The project is a subsystem of a larger project to design, build, and launch a nano-satellite. Design

requirements are given to the students: power, orbit, orientation, operational thermal requirements, survival thermal requirements, spacecraft IR backload. They analyze the surface treatment of the radiator for highly efficient heat transfer. The radiator area is optimized to meet system requirements. Heater power as a function of time over one orbit is calculated. Currently a paper study only, we will consider developing a build-test component of this project.

Composite materials are becoming more important in aircraft technologies. In the composite truss design and experiment, students have to design the lay-out of the epoxy glass fiber composite to sustain a defined load. They have the choice of 3 different diameter glass fibers. They have to calculate the modulus of elasticity and define a factor of safety for their design. The students receive a mold with minimal accessories; they are expected to design a feature to straighten the fibers, make the mold leak proof. Preparing the mold, fibers and two-component epoxy, and filling the mold exposes them to subtle differences between theory and manufacturing practice. Testing their designed strut to failure and evaluation the failure exposes them to testing methods, strength of fiber reinforced composites, and conveys an appreciation of Hooke's diagram.

We view the early use of system-level PjBL as an important innovation. Traditional engineering pedagogy holds that students cannot effectively design and build anything until they reach the "capstone", and can build upon layers of engineering theory. We have found that for the reasons discussed above that it is highly advantageous to introduce project-based learning in the first years of engineering education. In addition, the specific innovations that will be introduced include:

- The closer coupling of the engineering science fundamentals into the development of the project. Many early year design-build projects appear to give the students outlets for creativity, but do not couple well to the actual theory also being taught. This reduces the value as an introduction and motivation for deep disciplinary learning. We have explicitly sought to make the disciplinary coupling to the projects more explicit and real—such as the use of modern CFD codes such as X-Foils in the design of the wing of the RC aircraft.
- The integration of teamwork skills into the design-build experiences. Engineering education commonly asks our students to work in teams, yet often does not support this skills learning. We are developing a modular approach to supporting team formulation and operations.
- The integration of basic project management skills into the design-build experiences of modules. Like teamwork, we expect our students to acquire these skills, and must develop a scalable modular approach to delivery.
- Utilization of novel Web 2.0 methods that are intensively used by today's young adults, to develop projects by remote teams. These methods include among others wikis, blogs, and server-based file sharing such as Google Docs, Office Live, or SharePoint.

B. Third and fourth year project-based experiences

Third and fourth year project-based experiences reinforce learning, and develop student awareness and empowerment of newfound knowledge. We are developing third and fourth year experiences of two types. In one, the entire class work as one team in the execution of the project. In the second, smaller groups work in teams of 6-10 on the project. In most cases, the projects have a real customer, and deliverable "flying" article. Projects are interdisciplinary spanning modern aerospace disciplines (aeronautics, propulsion and structures, avionics, software, control and autonomy). The projects build awareness of other issues, including financial, regulatory, environmental and public policy, although this broader interdisciplinary

scope may not be a primary focus of every project. Example of laboratories and projects that are being developed or have been developed include:

- Development of UAV aircraft for tactical situation, including development of risk mitigation and safety planning for testing of student built UAVs
- Design, test and construct a hybrid propulsion system with the purpose of reducing fossil fuel dependency and increasing flight endurance for a baseline aircraft. This project is a collaboration of 2 Universities (Colorado and Daniel Webster College) where the aircraft frame is designed by one College (DWC) and the propulsion system by the other partner (CU)
- A solar unmanned aerial vehicle. Students modify a high performance sailplane by adding batteries and by integrating photovoltaics in the wings
- Flight testing of piloted aircraft
- Design a quad rotor vertical ascent and landing aircraft to carry dedicated payload
- Design of a flying wing aircraft with high aerodynamic efficiency. This project is an international collaboration with the Universities of Stuttgart and Sydney where the work "follows the sun"

As an example, at the University of Colorado, Boulder, students design, develop, and test a small unmanned aircraft powered by solar energy, with the goal to understand possible opportunities for solar powered flight. The military is interested in sustaining flight indefinitely through multiple solar periods. Perpetually flying aircraft have very significant applications, whether to serve as communications relays, earth imaging, or a science platform. High altitude solar aircraft are seen as low cost satellite replacements that can be easily refurbished with new sensor packages. The goal of this project was to modify an R/C sailplane by adding a structurally integrated PV energy harvesting system in order to increase the standard endurance of the aircraft to 250% from COTS value. This aircraft will be launched by hand by a single operator, while under the manual control of an r/c pilot operator. The aircraft will then be brought to altitude and then switched to an autonomous mode, where it will remain for the majority of the flight until it is switched out of autonomous mode and landed manually. In order to achieve this proof of concept, the aircraft will need to fulfill a number of secondary objectives. A robust communications system will be required in order to verify energy harvesting capabilities, control the aircraft and ensure that maximum endurance is attained. In-flight strain data will be gathered to verify that a sensitive photovoltaic system will be capable of enduring the stresses and strains exerted during flight. Finally, thin-film batteries will be integrated into the composite structure of the aircraft to demonstrate the weight and volume saving concept of integrated battery composites.

Such design would be extremely sensitive to subtle design changes, leading each design team member to maintain a thorough systems engineering perspective and keep their systems within the system design constraints. The members of this team need to understand that every subsystem can significantly affect other systems, and will need to account for all of the potential problems a design change can create. The technical activities include: ensuring that the wings and other structural components can withstand the forces exerted during flight; designing the control system to fly autonomously to predetermined locations; and creating an electric system design for the processors, motors, and servos. Embedding the batteries in a composite structure is a manufacturing challenge. This team's deliverables include an aircraft with the capabilities described above, as well as a means of preparing and launching that aircraft. The team also provides a portable ground station and telemetry system. The innovation in this project is to expand the understanding of the students of the sensitivity of design to in the introduction of new technologies (e.g. batteries and power conditioning).

A second project at the University of Colorado, HELIOS, was the design of a hybrid propulsion system for aircraft. This project was developed as a multi-university project to expose the students to delocalized design engineering as often used in industry practice. The senior student team at the University of Colorado designed a hybrid gas-electric propulsion system which combines the torque from a gas-engine and an electric motor at the propeller. This design led to the submission of a patent on the gearbox. A senior team from the Daniel Webster College designed the airframe after the requirements and constraints defined by the engine manufacturers at Colorado. The team of 4 students at Daniel Webster collaborated with two students at the University of Massachusetts at Lowell to manufacture the 13 ft wingspan airframe. They did preliminary testing of their airframe with an electric motor. Then the airframe was shipped to the University of Colorado and the dual torque propulsion system designed by the 7 students from Colorado was integrated and flight tested. The major successful learning experience in this project was the delocalized design effort and its related communication practices.

A current follow-on project to HELIOS¹⁴ is the project HYPERION¹⁵. This project is also a delocalized design project with teams on three continents: 1) A team of 11 graduate students at the University of Colorado, 2) a team of 7 undergraduate senior students, 3) a team of 4 graduate students at the University of Stuttgart, and 4) a team of one graduate and 5 undergraduate students at the University of Sydney. The project is about designing a blended wing body aircraft powered by a second generation of the hybrid propulsion system which is designed and developed by the Colorado undergraduate team. The project is partially funded by the Boeing Company, eSpace Inc. and the German DAAD. The structural and aerodynamic studies were done by the three universities and select elements were selected to be developed under a “follow-the-sun” design effort where the work was transferred to the next continent at the end of the day.

As a fourth example, a project on flight test engineering emphasizes the Operations in CDIO. Few US universities have formal courses in Flight Test Engineering, and these are commonly led by faculty members who have had direct experience as test pilots or test engineers. We have developed and refined a program that has learning outcomes that span foundational test processes: test planning, safety planning and risk mitigation, air data, instrumentation, flight conduct, data reduction and referral, specification compliance, and test reporting. Topics including performance, propulsion, structures, stability & control, and avionics are profoundly reinforced. Hence, even those schools without direct ties to the flight test industry can benefit from including such a project in their offerings. A related task yet to be done is to catalog best practices from among those schools actively conducting flight test engineering courses with manned airplanes and simulators, and development of new flight test exercises. The innovation in this project is developing approaches to teaching Flight Test Engineering in universities without experienced test pilots. We have enabled this by producing syllabi, procedural guidance, instrumentation requirements, budget and faculty competencies (and qualifications), and implementation issues.

The underlying innovation in these projects is the incorporation into the mainstream curriculum of the design, building and testing of realistic, in fact in some cases real, aerospace vehicles and systems and in one case a “global” design project. These are no paper study capstone projects, but drag the students through the stimulating experience of having to implement, operate, and deliver to the specification of a customer. This builds skills, reinforces knowledge and creates excitement. The additional innovations that would be introduced into these design-implement-operate experiences would include:

- Closer interaction with industry customers who define the needs and specification of the system, and the success of the system. Our industry-university steering group will identify a set of topics for each school year. The topics will be concept studies, exploratory studies, or alternative design studies, and should not be in the critical path of the customer. Students have the opportunity to interact with the sponsoring customer at several occasions.
- More “vertical integration” of the project between seniors, juniors, sophomores and alumni. This involves sophomores and juniors in tasks commensurate with their skills. They benefit from the excitement of the senior students, and they understand what issues the seniors face with their projects. Seniors are exposed to more explicit leadership and management issues. We have also demonstrated Web 2.0 technologies for engaging alumni in teams.
- Enhanced emphasis on operations, operational environments and risk assessment. Many design-implement programs involve flight test of UAVs, which should include mission requirements and plans for risk mitigation and safety. We are cataloging and refining best flight test practices from among schools actively conducting design-build courses with UAVs, so that students learn professional practice, while life and property are not put at risk.

C. Assessment

Besides being structured according to a common template all projects will be subjected to a common assessment template defined by CDIO outcomes. The first outcome in the template is linked to the technical discipline, in this pilot case aerospace engineering. Skills are for example: aircraft control, construction, propulsion, modeling and other analysis. For example Students in HELIOS, described above, will be required to develop and implement a wide variety of essential engineering project skills including: systems engineering, project management, design, manufacturing, analysis, testing, and more.

Assessment of team and individual student performance should emphasize the understanding of the fundamentals involved in a complex engineering project. Team performance metrics includes successful project management, effective systems engineering, good schedule maintenance and planning, safe fabrication and operation, useful testing and analysis, and overall project verification, validation, and success. Individual student performance metrics include student Peer Evaluations and overall contribution to the project as observed by close advisors. Success or failure is associated with overall project effort and analysis of results, and not dependent on meeting technical requirements.

In the fall semester, a PDD and CDD help to form the Project requirements, definitions, and overall scope. This is followed by a PDR and CDR to allow for advisory and/or professional review of the preliminary and critical designs accomplished by the team. The fall semester closes with an FFR to summarize all design work accomplished so far, and to detail the plans for the spring semester.

1. Project Definition Document (PDD)

The PDD is a written document detailing project objectives and scope. This document should help in developing top level requirements, concept of operation, and in identifying key technologies and required team skill sets.

2. Conceptual Design Document (CDD)

The CDD is a written document describing three concepts of system options. It should also detail the convergence on top-level system architecture and assess the feasibility of the project.

3. Preliminary/Critical Design Review (PDR/CDR)

The PDR and CDR are 20-25 minute oral team presentations to a panel of advisors or experts explaining requirements and preliminary baseline design with alternative options. This presentation also identifies and assesses project risks, prototyping, subsystem requirements, evidence of feasibility, and top level project plans with contingencies.

4. Team Managed Webpage

A team-managed website should be maintained to outline the details of the project and its team members and/or provide a central file management location.

5. Oral Assessment:

Interim Readiness Reviews 1 and 2 are two informal oral team presentations to an advisory board with the intention of providing updates on the project; Spring Project Review made during the 2nd semester is a final comprehensive oral team presentation.

6. Final and Interface Reports

Final reports at the end of each semester are designed to document all aspects of the project very carefully. They can serve in the evaluation of individual student performance if the assignment requires individual team members to assume select authorship on select chapters.¹⁶ Final reports are handed over to the project sponsor and owner to show validation of the initial project requirements. Interface documents are necessary when several teams collaborate on a project. For example delocalized teams need precise definitions of their charter. Collaborating local teams of e.g. graduate and undergraduate teams also need to define carefully their job charter.

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Reverse Engineering as a Didactic Tool in Nano- and Micro Technology

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ABSTRACT

This paper describes a student exercise in the field of nano & micro technology from the course "Solid State Electronics and Micro Technology". The course corresponds to a 10 ECTS point workload and is aimed at the bachelor student level. The timeframe for the exercise is 3x4 hours distributed over two weeks of study. The exercise is based on reverse engineering of a commercial piezoresistive pressure sensor and the students discover and analyse how this device is made. Based on their observations they calculate the expected performance of the device and compare it to the measurements they have performed. The use of reverse engineering as a didactical tool thus promotes active learning.

KEYWORDS

Active learning, reverse engineering, nano technology

INTRODUCTION

The Technical University of Denmark (DTU) provides a 10 ECTS credit course on solid state electronics and micro technology. The course is aimed for students attending the Physics and Nano Technology line of study and for students in the field of electrical engineering. The course covers the physics and technology of a range of devices including pn junction diodes, bipolar transistors, metal oxide semiconductor field effect transistors, and capacitive and piezo resistive micro electro mechanical systems (MEMS). The course uses the book *Semiconductor Devices* by Neamen [1] and a series of lecture notes.

The layout of the course is shown on Figure 1. The course consists of 26 lessons each lasting 4 hours. The first part of the course deals with an introduction to the theory of semiconductors including the concept of bandgaps, carrier distributions and transport equations for electrons and holes. This first part of the curriculum is assessed at a poster session where the students present different topics related to the theory part. This presentation counts 10% of the final evaluation.

The next part of the course covers pn-junction and Schottky diodes and fabrication of such devices. Again, this part of the course is summarised at a poster session counting 10% of the evaluation.

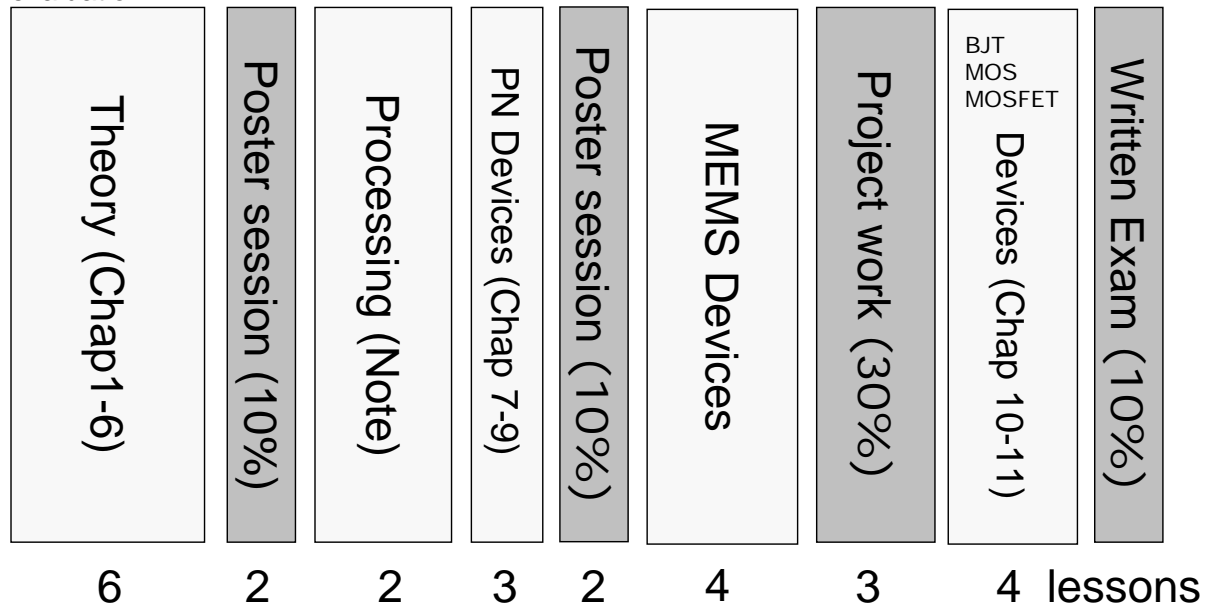


Figure 1. The course consists of different elements. The dark grey boxes are elements which are part of the evaluation.

The topic is now shifted to MEMS devices and for this part of the course a lecture note is used. The MEMS devices investigated includes piezoresistive and capacitive pressure sensors and accelerometers. Fabricating such devices can take months and actual design and fabrication of such devices is thus well beyond the scope of this course. To circumvent this situation reverse engineering of a commercial pressure sensor device from Honeywell, shown on Figure 2, is used for active learning. The students describe their finding in a report counting 30% of the evaluation. Finally the theory of transistors is covered and the final exam is a written test counting 50% of the evaluation.

LEARNING OBJECTIVES

During the course the students have learn about the theory for piezo resistive pressure sensors and have obtained skills that allow them to design such sensors using both analytical and numerical methods and sketch possible fabrication processes for such devices. These skills are now used to analyze how the pressure sensor works.

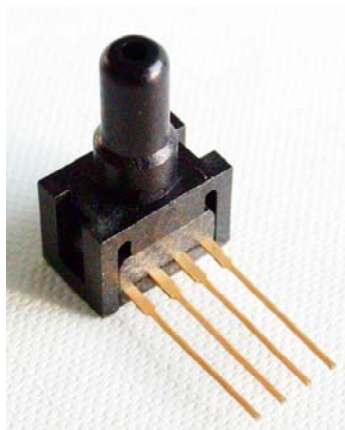


Figure 2. A pressure sensor made by Honeywell is used in the exercise. The advantage of this device is that it is possible to take it apart with simple means.

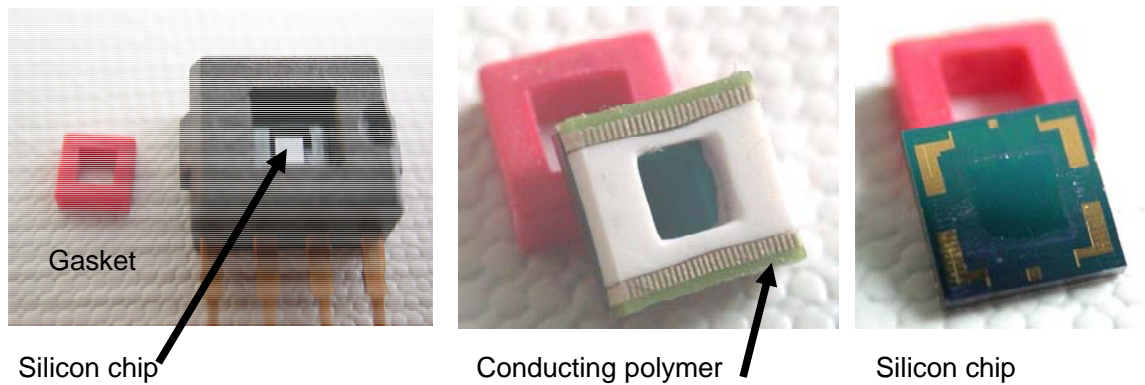


Figure 3. When the pressure sensor is taken apart the two gaskets and the silicon chip are clearly seen. One of the gaskets contains a conducting part serving to transfer the signal from the sensor to the electrical connections on the package.

The major learning objectives for this exercise are:

- Apply theoretical models to describe the performance of the pressure sensor
- Design a process flow for fabrication of the pressure sensor
- Describe how commercial sensors can be made in silicon
- Explain how packaging can be done
- Work in teams with a complex problem

The assessment is based on a report written by the team.

EXERCISE STRUCTURE

The students work in teams of three students and each team receive a pressure sensor together with the datasheet. Most students have never seen such a datasheet before and the difficulties in understanding the very short and concise text are initially overcome.

Measurements

In the first part of the exercise the students use the supplied datasheet to figure out how the electrical characterisation must be performed and they measure the (linear) output voltage-pressure relationship for the device and compare the measured sensitivity to the value in the datasheet. For this purpose the students have access to a pressure controller, a power supply and a multimeter allowing them to measure the output voltage of the device. The students discover a linear relationship between output voltage and pressure as expected from the basic theory. However, they also discover an offset, i.e. the output voltage is not zero for zero pressure. This comes as a surprise for the students and they discover that they need to take into account that in the real device, as opposed to the idealised device in the text book, not all piezo resistors have the exact same value of resistance causing the observed offset.

Discovering the packaging scheme

The next step is to find out how to take the device apart and examine its inner workings in detail. Inside the polymer encapsulation the students discover a silicon chip and two gaskets, as shown on Figure 3, performing the sealing of the device. One of the gaskets contains a conducting polymer that serves to connect the silicon chip to the electrical leads on the package and at the same time perform sealing. The students have never seen or heard about such a conductive gasket and have to discover how it works.

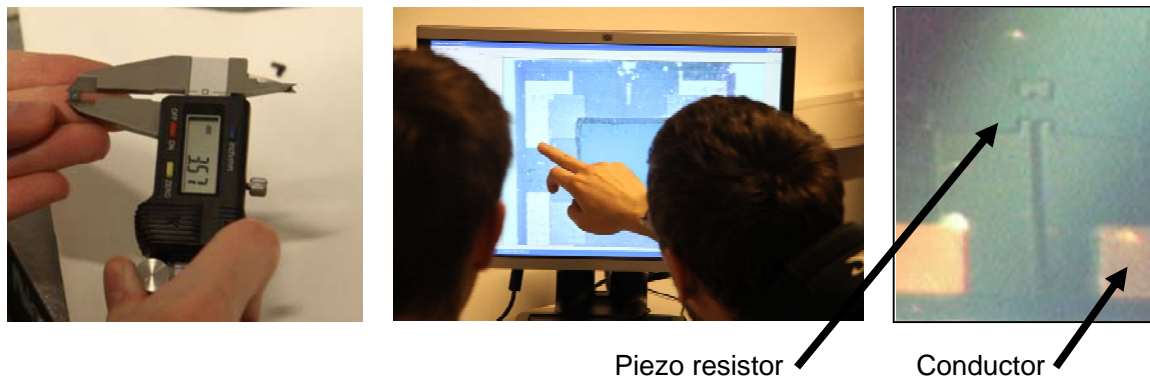


Figure 4. The size of the silicon chip is measured using a vernier caliper. The chip is inspected in an optical microscope revealing piezo resistors and conductors.

Analysing the silicon chip

The size of the silicon chip is measured using a vernier caliper. Using optical microscopes the silicon chip can be examined and the details of the design can be discovered. The students discover, that the hole which has been etched for the membrane of the pressure sensor has sloped sidewalls, and they can calculate the angle and conclude, using their knowledge of crystallography, that this corresponds to (111) planes supporting the conclusion that this is actually a silicon chip made on a (100) silicon substrate. On the surface of the chip several piezo resistors are seen, Figure 4, and it is concluded that these are connected in a Wheatstone bridge. Once the design of the device has been discovered the students perform measurements of the dimensions of the design, the silicon chip, location of the piezo resistors and other important details of the design.

Calculations

Based on the measurements of the chip the students perform analytical and finite element calculations to calculate the mechanical stress in the membrane. Combining these calculations with the theory of piezo resistance allows them to make a model of how the output voltage depends on the pressure. Thus, they can predict the performance of the sensor and compare these models to the measured voltage-pressure characteristics.

Figure 5a shows results from a finite element programme calculation.

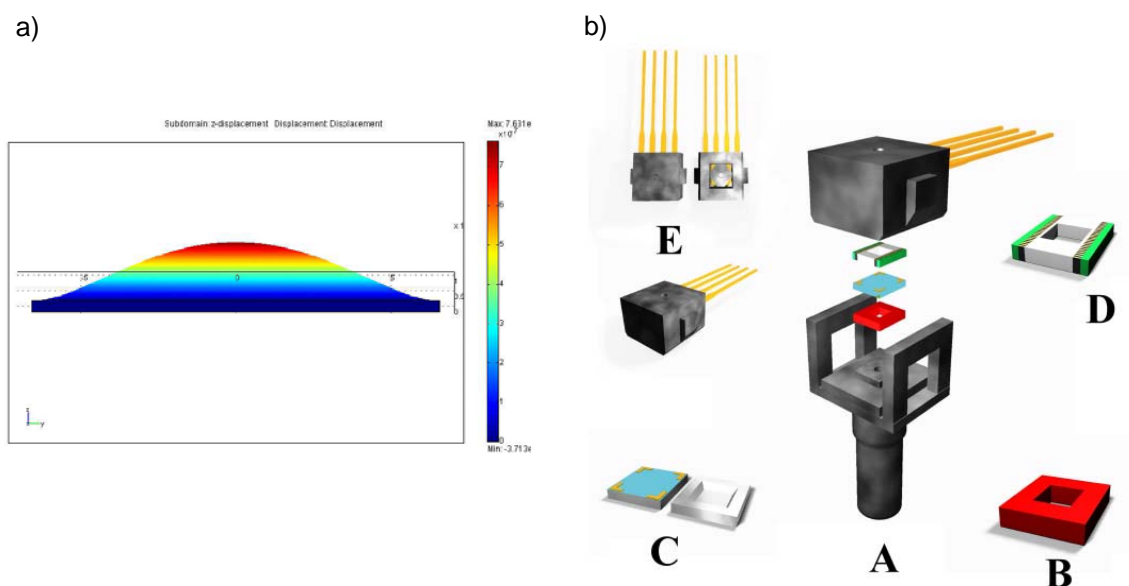


Figure 5. These pictures are from one of the student reports. a) Results from a finite element model showing the deflection profile of the membrane. b) Although making three dimensional sketches is not part of any course for the students they learn to use such tools by them selves and used it for illustrating their findings.

Report

Finally, the students describe their findings, Figure 5b, in a report which is evaluated and each team gets written and oral feedback.

ACHEIVEMENTS

The evaluation of the course reveals that the reverse engineering exercise is very well rated by the students. The really appreciate that they can work on their own hand and the process of discovery followed by calculations and predictions and comparison with measured data is described as being very inspiring. The students put a lot of energy and time into the exercise and this is reflected in the reports which are generally of a very high quality.

Table 1 compares the average marks for the reports compared to the average mark for the written exam and Table 2 describes the mark scale used. Although the marks vary somewhat from year to year it is clearly seen, that the marks for the reports are higher than those obtained at the written exam. This is attributed to the observation that the students are very active during the exercise. In evaluation of the report emphasis is on the methods chosen, the correctness of the analysis and the clarity of the report.

Table 1
Marks for the report and the written exam

Year	2010	2009	2008	2007	2006
Average grade - report	10,5	9,6	10,3	9,6	8,4
Average grade - exam	8,6	7,5	7,7	9,6	8,1

Table 2
Description of the Danish grade scale used in Table 1 compared to the ECTS grade system.

ECTS	Description
12	A For an excellent performance displaying a high level of command of all aspects of the relevant material, with no or only a few minor weaknesses.
10	B For a very good performance displaying a high level of command of most aspects of the relevant material, with only minor weaknesses.
7	C For a good performance displaying good command of the relevant material but also some weaknesses.
4	D For a fair performance displaying some command of the relevant material but also some major weaknesses.
2	E For a performance meeting only the minimum requirements for acceptance.
0	Fx For a performance which does not meet the minimum requirements for acceptance.
-3	-F For a performance which is unacceptable in all respects.

CONCLUSION

The advantage of this reverse engineering approach is that students over a short period of time can learn how all steps in the design and manufacturing of a device have been integrated into a product and at the same time develop their design and modelling skills by performing the same type of calculations that would be needed to design the device directly from a set of specifications.

Reverse engineering has also been used in teaching other fields such as Mechanical Engineering [2][3] and Mechatronics [4][5]. In conclusion, reverse engineering is also a very effective tool when teaching nano and micro technology.

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Inspiration of CDIO for Professional Master Training in China

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ABSTRACT

In this paper, we reviewed the CDIO Initiative from the perspective of Professional Master Training; conceived the training objectives of Professional Master based on the understanding of CDIO's core idea; designed Master's curriculum system and teaching methods to meet the new international requirements for professionals of high-tech development constructed graduate practice platform with the support of the practical results of Material Engineering graduates in BIT during the past three years to verify that they have reached the required training objectives.

KEYWORDS

Professional Master; Engineering Master; The CDIO approach; Cultivating objectives; Training program; curriculum system.

INTRODUCTION

Professional Degree is a qualification equivalent to the Academic Degree, with the course curriculum concentrated on a particular industry. Professional Master's Degree aims to train applied talents who have a solid theoretical foundation and could adapt to a specific trade or occupation. Based on the world's trend of graduate education and the reality of China's graduate education development, the professional education will become a priority and will be strongly supported and actively guided by the government in the coming years.

China introduced the system of professional graduate education since 1991. However, the program was only carried out in few subjects, and was based on part-time study. In 2009, in order to meet the urgent demands of national economic growth and social development for high-level professionals, the Ministry of Education decided to offer in large scale, a full-time master education program to professional postgraduates. In 2010, based on the existing 19 Professional Master's Degrees, the State Council Academic Degrees Committee considered and adopted another 19 subjects, and enlarge our Professional Master's Degree portfolio to 38, covering economy, management, education, engineering, agriculture, forestry, medicine and other fields. The Master of Engineering is the most important subject among all the Professional

Master's Degrees. According to the most recent statistics, the proportion of full-time professional postgraduate enrollment has reached 24.67% of the total postgraduate enrollment. This indicates that the development of professional graduate education in our country is accelerating and the structural adjustment of professional training is intensifying. Along with this trend, the structure of the graduate education, the education program of the Professional Master's Degree and its management system will also have significant changes and adjustments.

Compared to the academic education, professional education needs to have breakthrough innovations in the following areas: faculty team, teaching content & methods, research & professional skills training, laboratory establishment, evaluation criteria and methods, etc. The management system reform should also be considered. How to adapt to these changes and the new situation? The CDIO (Conceive-Design-Implement-Operate) Initiative for engineering education conducted by MIT and 3 other universities provide a valuable reference and experience to us.

In fact, since 2005, some colleges and universities in China have already started to learn and explore the idea & approach of the CDIO Initiative, with the support of the Ministry of Education: 39 institutions were approved by the Ministry of Education as pilots. However, the pilot program was only conducted for junior college students and undergraduate students and graduate engineering training was ignored in the program.

We believe that the CDIO Initiative is also highly valuable for the Professional Engineering Master's training, because the CDIO framework and approach to engineering education created by world leading engineering universities is a set of training model which meets the characteristics and regular growth pattern of engineering talent. It meets the needs of engineering professionals at different levels through a variety of teaching methods and aims to train innovative engineering professionals to achieve comprehensive development. We believe that talented people is hierarchical. Therefore, the concept of engineering professionals should also include a complete talent level system, i.e. not only a large number of professionals with expertise and skills in a particular field but also some top-notch experts with leadership quality and authority in the engineering field. The CDIO Initiative could be applied in the professional training for skilled workers and technicians in the undergraduate education for engineers, as well as in Professional Master's education for higher level engineers and experts. Therefore, it could be a very useful reference to domestic universities carrying out Master's of Engineering.

THE UNDERSTANDING AND INSPIRATION OF CDIO

CDIO (Conceive-Design-Implement-Operate) is actually the abbreviation of the whole process of modern industrial products, and represents an education reform model initiated by

MIT and three other universities of engineering and technology. The core content of CDIO model includes a training objective, a syllabus and a set of standards. Training objectives is to set up a goal for the training, the syllabus is the specific rules of "how to train persons", and the 12 standards is the test of the entire training process. Engineers trained by this model would be professionals that meet the needs of companies and the society. CDIO educational model inherits and develops from the European and American engineering education reform ideas during the past 20 years. More importantly, the core content of CDIO model and the relevant review criteria are proposed according to the requirements of some famous enterprises of the international industrial sector and the American engineering education certification standard. The implementation of syllabus, lesson plans and curriculum through each course, each module, every teaching link, will make sure the requirements on talents from enterprises will be included into the whole process. As a result, the CDIO model is very practical.

From professional postgraduate training perspective, we think the CDIO education model could inspire us from the 4 following aspects:

1. Whatever kind of talents should always have clear and precise cultivating objectives. For example the CDIO Initiative is to train engineers with four core abilities, which are: technical knowledge and reasoning ability; professional skills and moral qualities; interpersonal skills including teamwork and communication; conceiving, designing, implementing and operating systems in the enterprise and societal context.
2. Whatever kind of personnel training should focus on the process of education and the context. CDIO advocates student "completing the education process of conception, design, implementation and operation in enterprises and social environment".
3. Different personnel need to be fostered by different ways following different rules. Engineering professional postgraduate should develop their comprehensive engineering ability through engineering project practice.
4. We must pay special attention to "conceive" and "design" training, in order to bring up engineering and technical talent with the original innovation capability in the High-Tech field.

REFORM PROFESSIONAL MASTER TRAINING ACCORDING TO CDIO

Beijing Institute of Technology (BIT) is a key university of science and engineering in China, shouldering the mission of cultivating fundamental scientific researchers for nation and institution. At the same time, it is also responsible for cultivating engineers of technology and engineering for the society and enterprises. BIT begins postgraduate education since 1955, and became one of the first batches of Chinese doctoral degree awarded organizations in 1981. After more than 50 years of development, BIT has supplied the society with hundreds of thousands of scientific and technical talents at different levels in different fields. In recent years, China adjusted the structure of postgraduate education, carried out a full-time master education program to professional postgraduates in large scale. BIT is one of the pilot universities, this group of students will graduate in July 2011, which means the

reformation has gained preliminary achievement.

1. Conceive the Cultivating Objectives and Plan the Scheme for Professional Master

The cultivating objectives influence directly the college's cultivating quality of talents and the quality of a training program plays a fundamental role. In order to ensure the quality of Professional Master, our school referred to the Professional Master's cultivating plans of more than ten domestic famous universities as well as the ideas of engineering education in foreign colleges, proposed the guidance which is used to establish Professional Master's training program: establish the "student-centered" concept of modern education, set up international and leading consciousnesses, adapt to the needs of social development actively, locate the objectives and characteristics of different subjects scientifically. Professional Master's cultivating objectives should have international perspective; should be clear and accurate; ; should be practical, , measurable, and achievable; and it is required to embed cultivating objectives into training program's all links, especially the curriculum system part. For example, the professional master's cultivating objectives of "Material Engineering "in our school expressed as: This discipline cultivates engineering and technical talents in Materials science and engineering field who are high-level, professional, and suitable for new international requirements. Degree's winners should have a solid theoretical foundation in materials science and engineering, understand the development trend of the discipline, has the ability in engineering design and undertaking technical work independently, master the material synthesis and preparation techniques, material properties testing and analysis methods, and necessary calculated and experimental skills, have capabilities to develop new materials, new products, new processes, new equipment, meet the high-tech industry needs for high-level materials engineering personnel. Be able to use English skillfully to read specialized literature and to communicate with international peers. Have rigorous and realistic scientific attitude and innovative spirit, professional ethics.

2. Design Curriculum System for Professional Master's Degree

Teaching is the main way to acquire knowledge and is the basis for capacity-building. When designing the curriculum system for Professional Master's Degree, we focus on offering graduate students the ability to obtain professional knowledge, practical application, research creatively, and organization & communication skills. Based on the research of graduate courses of domestic and foreign universities, courses are classified as 4 types: basic knowledge in this field, engineering technology, the field frontier and interdisciplinary. Among them, basic knowledge courses in the field including science foundation knowledge & engineering foundation knowledge are mainly the basics of the discipline to supplement & update knowledge on the undergraduate level and improve graduates' theories level; engineering technology courses are professional knowledge what will help improve the practical skills , focusing on students' systematic thinking and ability to solve practical problems; frontier courses reflect the latest research achievements and development trends in order to strengthen students' understanding for frontiers, broaden their knowledge and enhance their technological innovative capacity; interdisciplinary courses required for the

project are mainly knowledge of related areas, focusing on management, law, culture, humanities etc., in order to improve the overall quality and capacity. Courses are also classified as required and elective, each containing a corresponding course (see Figure 1).

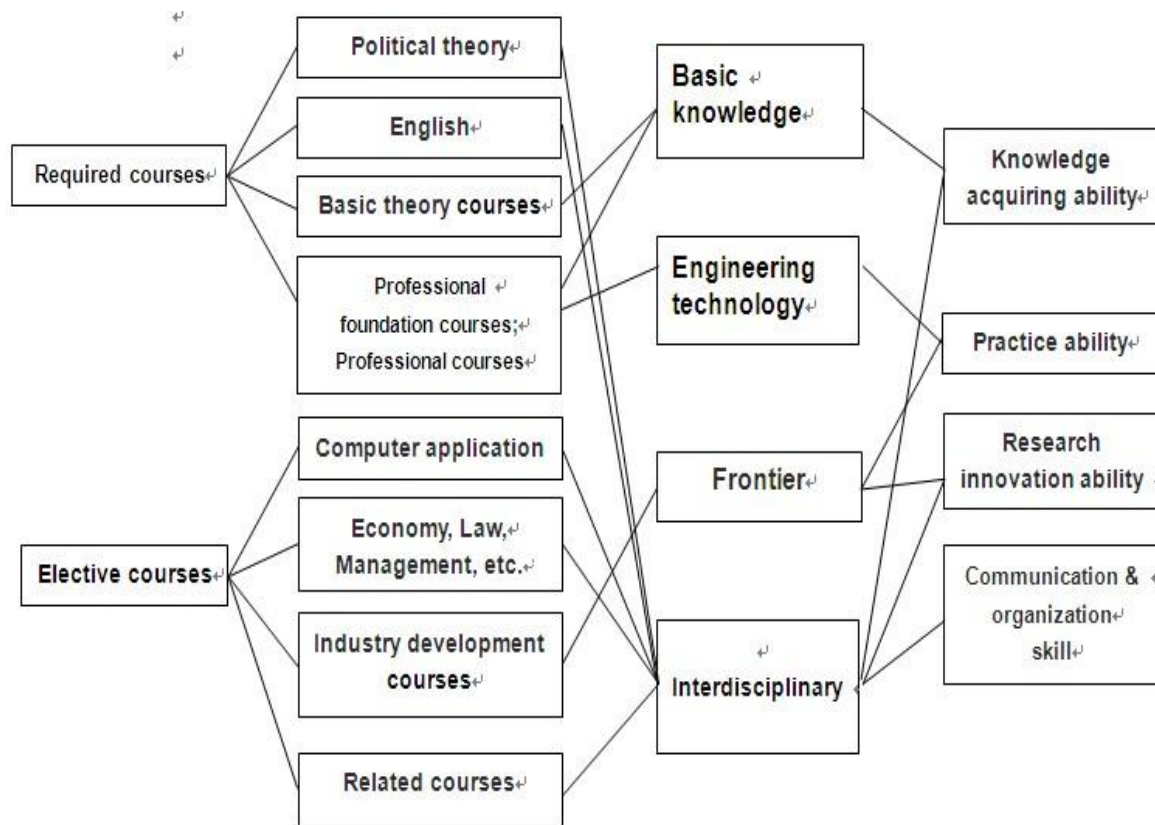


Figure1. Professional postgraduate course classification and ability relationship chart

Through the different categories of courses, we target to train graduate students to master the four abilities mentioned above. Required courses reflect the master-level core content in the subjective field, and the subject's characteristics of our school; elective courses fully reflect individual research needs of different research directions and different employment directions, also consider the needs of interdisciplinary or equivalent educational graduate for knowledge-docking. Total credits required are 34, in which required courses represents 14 credits, 41% of the total; elective courses represents 16 credits, 47% of the total and supplementary courses do not have credit; Practice counts 4 credits, 12% of the total. (See Table 1)

Table1: Materials Engineering Curriculum for Professional Master's Degree

SN	Category	Course name	Credits	Notes	
1	Field basic courses	Numerical analysis	2	Required	
2		Materials science foundation	0	Supplementary	
3		Modern material analysis testing techniques	3	Required	
4		Solid State Physics	3	At least take 8 credits	
5		Solid Chemistry	3		
6		Rubbery polymers physics	3		
7		Polymers synthetic chemistry	3		
8	Advanced Organic Chemistry	3			
9	solid-state phase changes	3			
10	inorganic nonmetallic materials	3			
11	Technology application courses	Material processing theory	3	At least take 8 credits	
12		Elastic-Plastic Mechanics	3		
13		Electrolyte physics and electrolyte materials	3		
14		Functional Materials	3		
15		Resin Matrix Composite	3		
16		Combustion material science	3		
17		Material modifying and surface engineering	2		
18		Mold design theory and method	2		
19		thermodynamics of alloys	3		
20		Defect diffusion and sintering	2		
21		Plasma chemical and technology	3		
22	Field frontier courses	Materials interface science	3	At least take 8 credits	
23		thin film technology	3		
24		Nano materials and physics	2		
25		Progress in Materials Science	2		
26	Interdisciplinary courses	Material science Computer Numerical Simulation	3	At least take 8 credits	
27		Intellectual Property Law	1		
28		Material processing computer simulation and applications	2		
29		Review of literature retrieval	2		Required
30		Dialectics of nature and science and technology revolution	2		Required
31		Scientific socialism and the economy	1		Required
32		The first foreign language (English)	3		Required
33	Professional Foreign Language	1	Required		

3. Build Platform for Practice, Train Professional Master's Conceiving and Designing Abilities

Restructuring of graduate education system further complicates the exiting diversified master's level graduate education, especially for the just started professional graduate education. We are actively exploring the potential environment which will be more favorable to their independent study and the development of their innovation abilities. Undoubtedly the background created by social, business and school together is the best environment for cultivating graduate's engineering comprehensive ability and innovative ability. In the process of building this environment, we tried to use the current available resources in our school as much as possible, we managed to break the restraints from the past concept of laboratory construction, utilization and management. We organically combined the advanced experimental equipments and software scattered at each lab through net and used the national lab rewarded by Education Ministry as the main body. In such a way, we created the open-share-lab, where each lab can run independently and can run in union. At present, some labs have already achieved the basic functions of remote experiment and have already gained certain achievements, such as the graduates open lab of intelligent control and decision of complex system based on net; the graduates open lab of digital information processing; the graduates open lab of design, simulation and test of spacecraft; the simulation lab of explosion science of technique, the graduates open lab of collection, transmission and processing of electronic information, the graduates open lab of design of new concept vehicle; the lab of environment engineering and science; the graduates open lab of management, decision and innovation; the graduates open lab of interaction art of digit and media; the graduates open lab of simulation and emulation of material; the virtual platform of real-time emersion of the process and flow of metallurgy.

Take Materials Simulation Laboratory of School of Material for example, it is mainly to train and increase the postgraduate's capacity in engineering, especially in terms of research for high-precision material processing simulation. Simulation platform is mainly composed of a local area network including server and terminals, and equipped with advanced software, such as material processing molding simulation software, material data calculation software, thermodynamic database, multiple phase diagram calculation software etc. Automatic security management systems are also installed for managing and controlling the use of computers. In materials simulation laboratory, graduate students research and develop new materials and research the control of microstructure and properties of materials in accordance with the material usage requirements, using knowledge of physics, chemistry, and materials science, computer simulation software and materials database. Reproducing complex material processing conditions through simulation on the computer at anytime, can help students get abundant data information for problem analysis and design optimization and avoid a lot of blind experiments. The laboratory has attracted a lot of graduates here to practice and learn autonomously, where they applied and tested their professional knowledge, practiced engineering operations, learned using powerful software to analyze and solve practical problems. Laboratory staff provides students with various

services including detailed answers to questions, so that each participant is able to use the laboratory skillfully. In recent years, students have successfully completed a lot of researches here, many of which are national projects or cooperative projects with famous enterprises. More importantly, a large number of talents were trained here to master advanced science and technology and meet the demand of enterprises and the society.

For example, a Fresh professional master graduates of materials engineering, completed the courses excellently, selected solar cells material as research topic under the guidance of the instructor, researched the transformation efficiency of new materials using the advanced technology of the laboratory and found method significantly improving the efficiency of the new material through repeated simulation, analysis, demonstration in just two years. As a result, he signed a contract with a well-known enterprise before graduation. This is just one of many training cases of professional graduates. Many examples illustrate that students should start research projects as soon as possible. By a combination of instructor's guidance and a laboratory platform equipped with advanced technology, they would grow rapidly through the CDIO practice.

Meanwhile, we also strived to create a soft environment for students' development, including arranging a series of lectures; encouraging students to attend academic conferences; inviting domestic and foreign celebrities, the elite in famous enterprises, world-renowned scholars to do special reports on international political, military and economic tops, technological frontier and the latest trends. The purpose is to extend graduate students' international perspective. In addition, we arranged a series of activities such as quantitative reading, group discussions, oral reports in the training session, to train graduate students' critical thinking which is an important part for them. Some graduating students said: "In the days of getting my Professional Master's degree in BIT, I feel the monthly subject reports benefit me mostly, a lot of reading and the debates in seminars also benefited me deeply."

CONCLUSIONS

In 2009, Engineering Master Plan Enrollment of BIT is 310, covering 10 majors. This group of students that will graduate in July 2011 have overall achieved the training program's objectives. About 20% of them prepare to study for PhD in China or abroad, the other 80% of them prepare to start a career, and the signing rate achieved the average level of academic Master in previous years.

Based on the CDIO's idea and our understanding & practice, BIT formed a detailed training program for Professional Master, having the training objectives as a guide, the curriculum as core, including the process of training and evaluation requirements.

This article mainly focuses on BIT's practice to establish professional master's training program according to the CDIO's idea. However, because the cultivation of Professional Master is just beginning and have inevitable inertia with Academic Master Program, there are

still lots of questions to be answered surrounding the cultivation of professional master, such as school-enterprise cooperation, the social practice, faculty construction, which will explore and research in the future.

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Hyperion Flying Wing Aircraft Technology

Poster Presentation



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ABSTRACT

Student engineering teams develop a 3m scale model inspired after the NASA-Boeing X-48B blended wing body to use as a test bed for advanced technical studies. The design concept, named Hyperion, implements a novel hybrid gas/electric power train as a green aircraft technology. The aircraft serves as a test-bed for research and development in the following focus areas: aerodynamics, structures and materials, weights and mass properties, handling and control, flight mechanics, and efficiency improvements on performance. The University of Colorado's collaboration with the University of Stuttgart, Germany, and the University of Sydney, Australia, allows the global project team to work full 24-hour days on the project by transitioning every 8 hours. Thus, the project teaches essential global industry skills in project management and systems engineering through long-distance design collaboration with multidisciplinary and multicultural teams of graduate and undergraduate students located around the world. Lessons learned will be valuable for the students and industry.

KEYWORDS

Global design, international teamwork, aircraft design, green aviation

INTRODUCTION

The goal of the Hyperion project is to conceive, design, implement, and operate an aerial platform to investigate new technologies for improvements in capabilities and efficiencies. The growing UAV and commercial airline industries are forcing improvements to be made in order for the growth to be sustainable. A second goal of the Hyperion project is practice international collaboration in academia by providing an industry simulated working environment. Improving the educational experience of the next generation of engineers is paramount to providing the workforce necessary to achieve the challenges ahead in industry. The newly designed aircraft offers efficiency improvements over conventional designs and serves as a platform for hybrid engine development. This paper will merely highlight the foundational design aspects of the Hyperion aircraft, which has been completely designed and built in the span of 9 months.

AERODYNAMIC DESIGN

The Hyperion aircraft is a test platform for a variety of high-efficiency and cutting edge aircraft design ideas. In order to maximize aerodynamic performance parameters, a flying wing was designed using the NASA/Boeing X-48 as inspiration. The result is a new aircraft entirely, seamlessly blending different two different airfoil sections to maximize the lift to drag ratio, while still maintaining correct trim, shown in Figure 1.

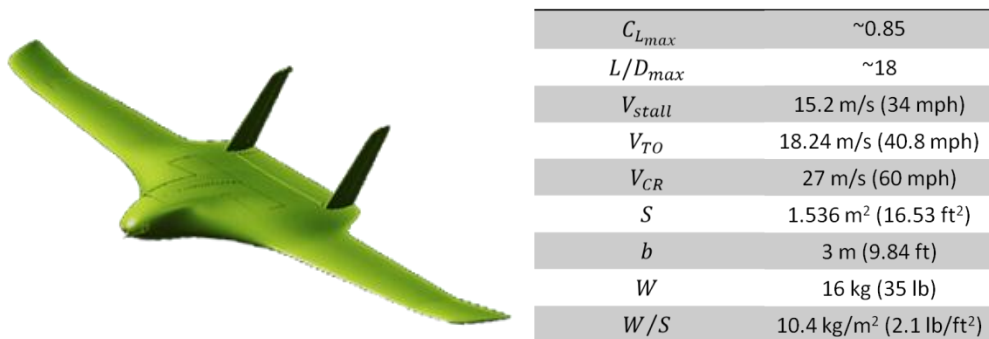


Figure 1. The Hyperion Aircraft and Performance Specifications

The aircraft has a 3 meter wingspan, will cruise at speeds of approximately 30 m/s, and is controlled by a single rear elevator, two ailerons, and two rudders. An automated, iterative script was developed in XFOil, Athena Vortex Lattice (AVL), and MATLAB to optimize winglet design. The final design employs raked wingtips, which achieve increased span efficiency and L/D without the risk of stall at low Reynolds numbers. An H-tail was selected using similar methodology, while considering directional stability and piloting simplicity.

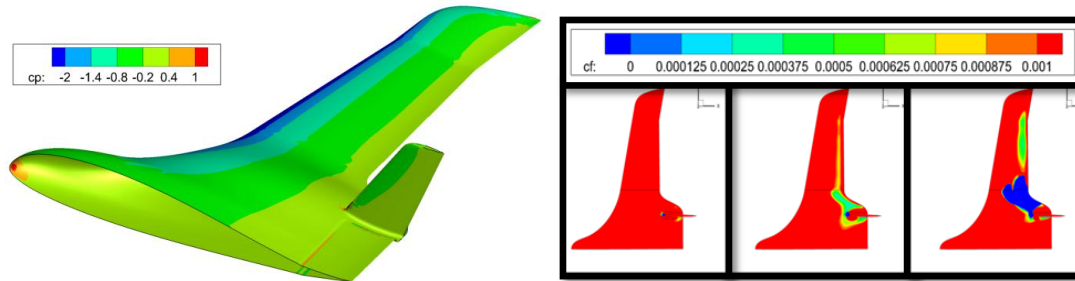


Figure 2. University of Stuttgart CFD Results

In addition, the University of Stuttgart, Germany has performed a 3-D computational fluid dynamics (CFD) analysis of the airframe to better predict performance using a proprietary CFD code. The CFD, pictures shown in Figure 2, employs the implicit backward Euler method, and is used to refine lift and drag predictions, and to quantify stability derivatives required by the flight control system. Furthermore, CFD has been performed to quantify the influence of the engine propeller on the flow field and the lift and drag curves of the aircraft. The CFD analysis was compared to the wind tunnel tests performed at the University of Sydney, shown in Figure 3.

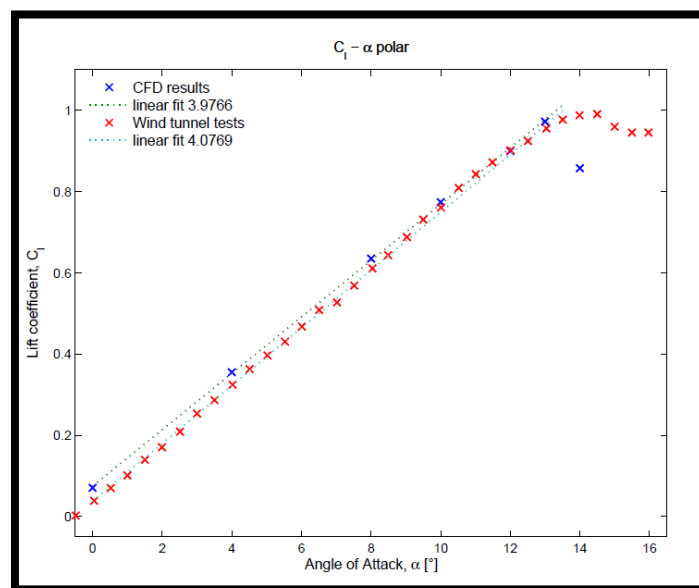


Figure 3. CFD and Wind Tunnel Results Comparison

STRUCTURAL DESIGN

In order to minimize the mass of the aircraft, the vast majority of Hyperion is constructed from composite materials. Two carbon-fiber spars bear the loads in each wing, and transfer stress to four carbon-fiber foam-core ribs, shown in Figure 4. These ribs also serve to maintain the aerodynamic shape of the skin. Finite element analysis (FEM) was performed to validate rib and spar integrity with safety margins against expected loads. This structure was manufactured by a team at the University of Colorado, while University of Stuttgart students were simultaneously working on the molds to complete

the fiberglass skin layup, which is constructed from a layered fiberglass with a foam core.

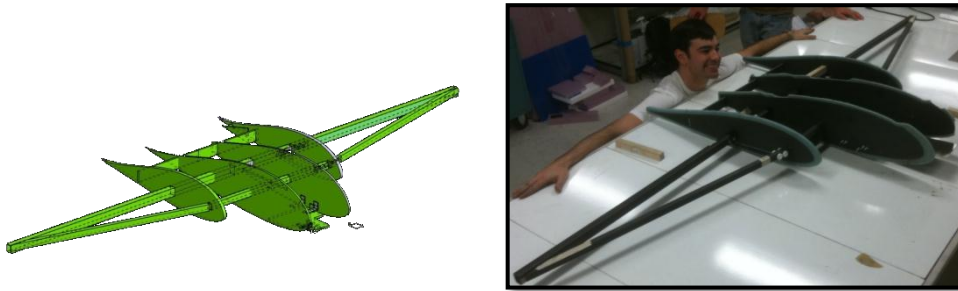


Figure 4. Internal Design & Structure

Classical laminate theory was used to predict material properties of the skin laminate, while a Bernoulli beam theory approach yielded the occurring bending stresses in the skin shell as can be seen in Figure 5. This analysis establishes confidence in skin defence against buckling under aerodynamic loads.

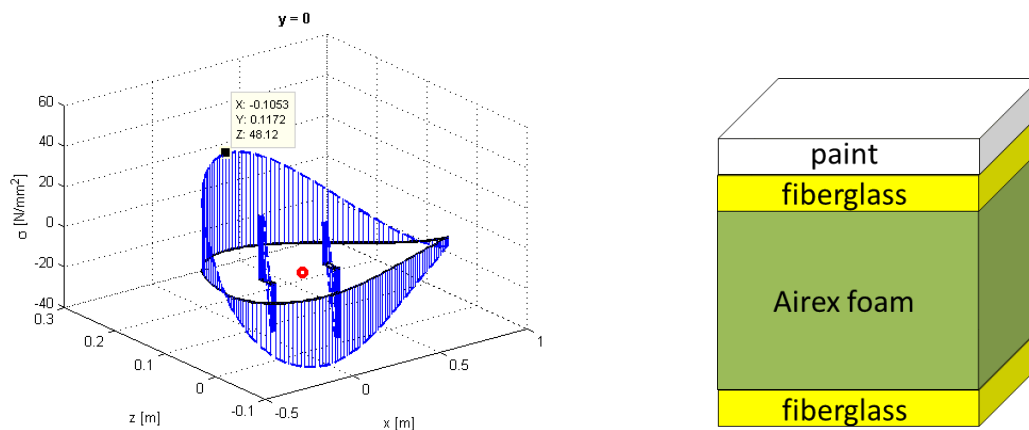


Figure 5: Skin stiffness analysis and composition.

PROPULSION

The Hyperion is powered by a one-of-a-kind hybrid gas-electric engine based on a proprietary design developed at the University of Colorado in 2009-2010, now licensed by Tigon Enertec, Inc. A patented gearing system seamlessly blends the torque from an internal combustion engine and an electric motor, which are arranged in an in-line configuration to maintain aircraft-friendly symmetry.

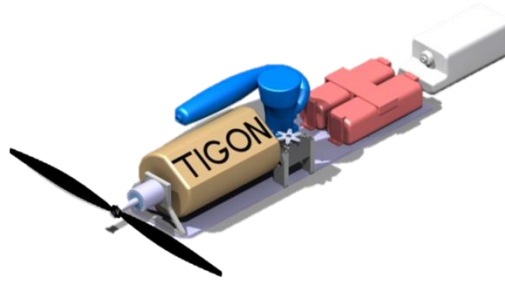


Figure 6. Hybrid Propulsion System

This propulsion system, Figure 6, allows for the aircraft to fulfill concepts of operations of both long-endurance and quiet loiter UAV platforms without sacrificing performance. Furthermore, the engine has demonstrated fuel savings of approximately 15%.

ELECTRONICS AND FLIGHT CONTROL

The Hyperion flight control system is designed to combine pilot control input with onboard guidance, navigation, and control data to successfully fly the aircraft. Two onboard batteries and a consumer off-the-shelf (COTS) R/C communication and data logging system support this function. The control system architecture is modeled in the Matlab/Simulink environment for simulation and development. As flight control code matures and hardware is acquired, hardware-in-loop (HIL) tests are performed to verify and improve models, optimize controller performance, and to identify and debug integration issues. Upon successful integration of the flight code and hardware on a test bench, the code will be recompiled into an embedded format and loaded onto the aircraft for additional testing and flight.

The flight controller performs stability augmentation using state variable feedback (SVF), where the aircraft states are monitored by two onboard sensors. This control scheme allows for the computer to make updates to aircraft attitude rapidly in order to more accurately track pilot input commands. Parameters for the plant matrix of the state-space controller are determined using computational fluid dynamics from the German team, empirically from University of Sydney wind tunnel data, and experimentally using aircraft geometry. A block diagram illustrating the control system architecture is presented in Figure 7.

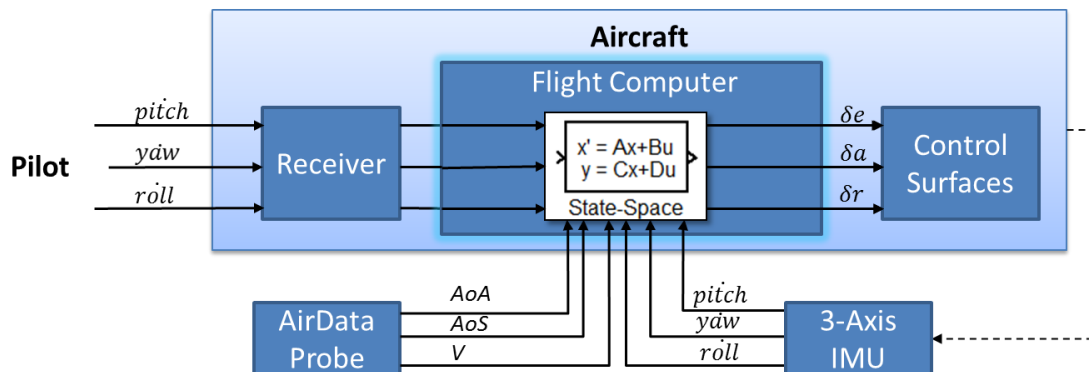


Figure 7. Left: Hyperion State-Space controller

INTEGRATION AND TEST

For a project of this complexity and low tolerance for failure, high-fidelity simulation and hardware-in-loop (HIL) testing is required to ensure success. Several “flat-sat” integration models have been constructed, to aid in electronics integration and test, as well as internal layout design and mass balance. Furthermore, using the MATLAB simulation/flight software package outlined previously, a test platform can be constructed to simulate aircraft performance with the controller and sensors engaged. A block diagram of the Hyperion Test Platform is presented in Figure 8. In order to facilitate international testing and collaboration, the test bench can be operated over the internet by the Australian and German teams using a remote desktop tool. The operator then configures the simulation to test a particular behaviour or set of behaviours and engages the bench.

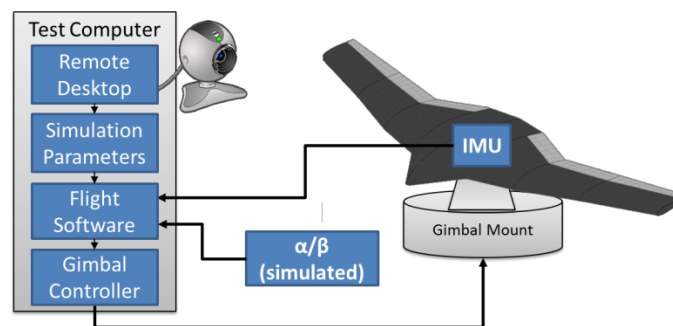


Figure 8. Hyperion Test Platform

This HIL testing scheme allows for a majority of hardware integration problems to be detected and eliminated prior to flight, greatly increasing chances of success. Furthermore, the Hyperion Test Platform allows for operators on all three international teams to perform statistical stability and performance analysis under a variety of highly configurable conditions around the clock. Large numbers of these simulations can be used to perform Monte-Carlo analysis, allowing the team to quantify confidence intervals and probabilities of failure during critical flight regimes.

Furthermore, a number of ½ scale prototype aircraft have been constructed for flight testing. These aircraft were created from foam blocks and carefully hand-sanded to achieve dynamic scaling of the Hyperion’s geometry.

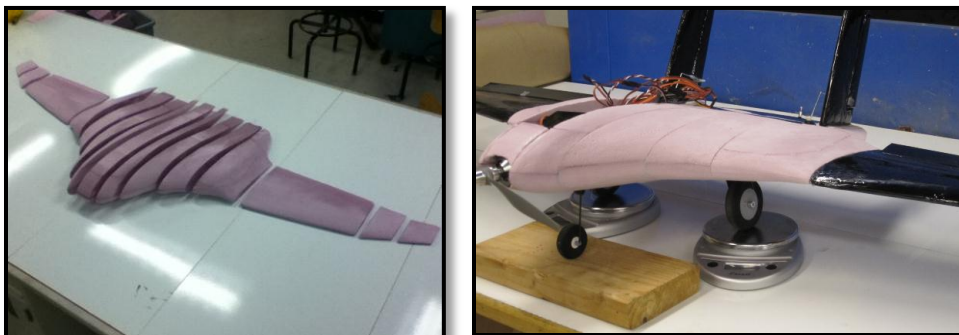


Figure 9: Half-scale flight test prototype.

These prototypes serve to acquaint the pilot with aircraft performance, mitigating inherent risks associated with flight testing the full aircraft in the Spring of 2011.

CONCLUSION

Hyperion is on schedule to complete construction and flight testing in April of 2011 in Colorado. The resulting aircraft will be the epitome of cutting edge aircraft design, and the result of an international collaboration designed to expose students to industry practices and a variety of engineering cultures.

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TEACHING INTERPERSONAL SKILLS IN AN INTERNATIONAL DESIGN-BUILD COURSE

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ABSTRACT

The Technical University of Denmark (DTU) and Helsinki Metropolia University of Applied Sciences (Metropolia) started the CDIO concept in the autumn of 2008. The aim with this was to reform the B.Sc. courses to guide students to become better and more efficient engineers. The working conditions of a typical engineer involve many other fields than just those requiring technical skills. Interpersonal skills are becoming increasingly important, including communication, teamwork and leadership. The purpose of this paper is to describe the co-operation between DTU and Metropolia on the development of an International Communication Course for the engineering students and to emphasize the importance of including a course like this into the CDIO concept, to be worked on in the process of further development. The course described in this paper is a strictly non-engineering course in communication; it is special in that its chief purpose is to bring into focus the fact that students have to take an active part in the exercises as well as involve themselves in the interactive communication process. This is in stark contrast to a teacher giving lectures about communication, leaving the students passive listeners. The personal involvement aroused a negative reaction from several students at the beginning of the course however, during the one- week course the students gained a better understanding of the importance of learning how to communicate appropriately. Altogether, the four key questions dealing with the quality of the course show a very high satisfaction with the instruction. The grades one and two (1 best/very much, 5 worst/very little) of the responses to these four questions are ranging on average from 69.5% to 88% (on a yearly basis). The positive responses indicate that the students are very satisfied with the course recognising the need for education on international communication.

KEYWORDS

Active involvement, communication, exercise, interpersonal skills, optimal teaching, personal development.

INTRODUCTION

It is very important, when giving high quality teaching at university level, to present the lessons in varying ways with different kinds of teaching activities [1] [2] [3] [4]. For this reason the teacher needs to have a wide repertoire of teaching methods and study forms for different occasions [5]. These can be used by the teacher depending on content, context and objectives, and the students can apply the most suitable method at any given time.

One way to meet this challenge and create a greater variation is the implementation of the CDIO concept. This was introduced in the autumn of 2008 at the Technical University of Denmark (DTU) [6] and Helsinki Metropolia University of Applied Sciences (Metropolia). The main goal set for starting the CDIO concept was to work on the process of reforming the B.Sc. courses with the purpose of training students to become better and more efficient engineers. The CDIO Syllabus consists of four parts [7]: 1) Technical Knowledge and Reasoning, 2) Personal and Professional Skills and Attributes, 3) Interpersonal Skills: Teamwork and Communication, 4) Conceiving, Designing, Implementing and Operating Systems in the Entrepreneurial and Societal Context.

Figure 1 shows that the working conditions of the typical engineer will nowadays include many other competencies than just the hardcore technical skills – sections 2.1, 2.2 and 2.3. It will also include personal and professional skills, multidisciplinary teamwork, communication, communication in a foreign language and leadership – sections 2.4, 2.5, 3.1, 3.2 and 3.3. For this reason it is important that modern education for engineering students meets the demands of today's business life, where the engineer has to solve both technical and humanistic problems, thus creating good results from an all- round perspective. For this reason it is important to pursue interpersonal skills in engineering education – there, however, is a tendency in engineering educational systems to give the implementation of this pursuit a lower priority.

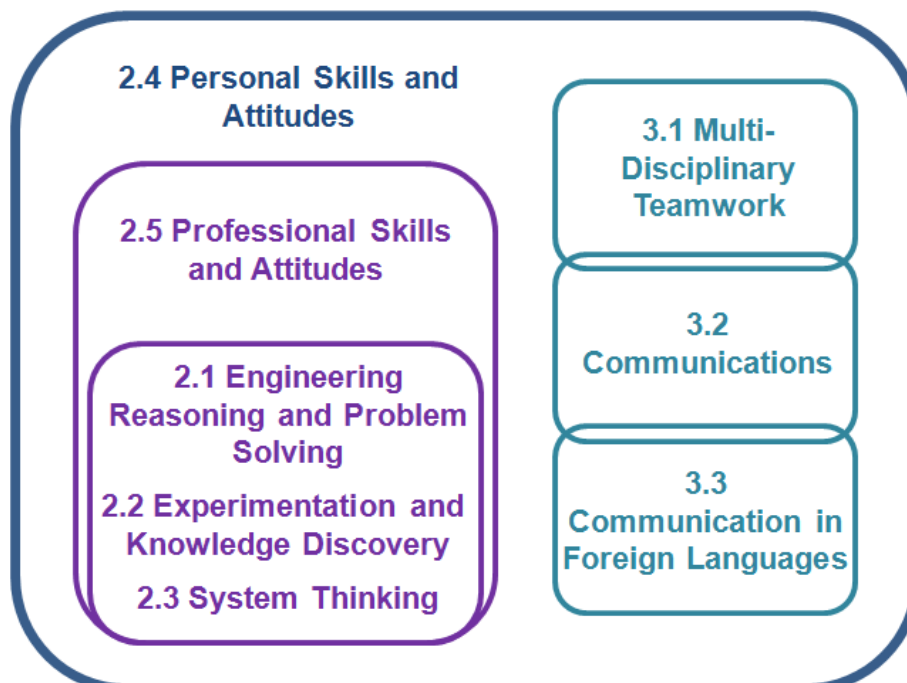


Figure 1 [7]: The CDIO Syllabus: Personal, Professional and Interpersonal Skills

J.E. Christensen has been involved in the work of an effective implementation of CDIO on a practical level at DTU Civil Engineering, which has given rise to an evaluation method [8]

making use of a combined paper and electronic questionnaire. Another way of improving the quality and ideas in the CDIO development is through International Co-operation, which involves participation in CDIO congresses. As an outcome of *the 5th International CDIO Conference, Singapore Polytechnic, Singapore, June 7 - 10, 2009* [9] Jørgen Erik Christensen has established co-operation with Programme Director Markku Karhu from Metropolia to develop a course in International Communication (taught in English), with the focus on communication, teambuilding, networking, positive behaviour and other interpersonal skills [10].

Since 1992, one of the strategic objectives of Metropolia has been to be an international educator of engineers offering the entire degree programme in Information Technology in English. Meanwhile Metropolia has started six new programmes in engineering with English as the instruction language. The objectives of the International ICT (Information and Communication Technology) week for the first year are the following: IT students are encouraged (1) to enhance their communication skills among local (Finnish speaking) and international (English speaking) students as well as (2) to embrace engineering reasoning and teambuilding. A major challenge is posed by the fact that there is hardly any communication between students of the various nationalities. The International ICT Week format is seen to be one way to break the barriers between different nationalities. This activity was commenced in February 2009.

The co-operation was started through the invitation of Prof. Christensen to give a course in International Communication at Metropolia during the International ICT Week, 15-19 February 2010. This was followed up in the Metropolia Summer School, 23-27 August 2010 and the International ICT Week, 21-25 February 2011 held both at Metropolia. During these courses valuable information was collected and used for further development of the course. The course is based on the students making their own experiences while doing different communication exercises.

In order to improve the course student evaluations have been implemented. The evaluations have given valuable information for improvements. In general the results show a very high satisfaction and the students' preference for the active learning approach. The students are highly committed and the course arouses added interest in studying team-building and interpersonal skills.

The principles developed have been used in a CDIO International design-build course in an Erasmus intensive programme (IP) entitled "Developing Open Source System Expertise in Europe (DOSSEE)" [11].

THE PURPOSE WITH THE PAPER

The purpose of this paper is to emphasize the importance of including international communication courses in the CDIO concept while reforming the curriculum in B.Sc. education. Valuable information has been collected from the course evaluations conducted through paper questionnaires, and prompted by these; suggestions will be made for changes to improve the course. The design of the course will be discussed and the actual success factor described based on the paper questionnaires.

Since it has been the objective of Metropolia to enhance the communication skills between local (Finnish speaking) and international (English speaking) students, one focus of this paper has been to analyse how the International Communication Course can support this requirement and develop it further.

DESCRIPTION OF INTERNATIONAL COMMUNICATION COURSES

Metropolia is a technical university and the section that is hosting the course is designated for IT students. Many have major difficulties with communication, as will be described later in the section "Example of an exercise from ICC – Deflection". The students come from numerous countries worldwide, including Vietnam, Korea, Bangladesh, Nepal, Kurdistan, Russia, Nigeria, Kenya, Zimbabwe, Ghana, Morocco, Ethiopia, Costa Rica, different European countries, and of course many come from Finland. The first hours of the course are spent on ice-breaking exercises. This is to give the students a possibility to get to know each other, whereby seated at a proper distance from their partner they will start working having greeted one another in a manner peculiar to each country. General modes of communication are taught along with many exercises:

- Confluence – the mental process whereby you try to conform to the behavioural pattern of your environment to avoid conflict – an important issue when you are an engineer working in a foreign country. Working on this subject means making the student aware of what he/she really feels and when he/she is adapting in perhaps an unhealthy manner.
- Perception – the brain can perceive 11.000.000 impressions per second most of them through sight, but all these impressions are filtered by the brain so only a few of them are conscious. The point is to make the students aware of the fact that two persons can share the same incident, and still have different experiences.
- Figure/background – is a kind of perception but deals among other things with the fact that what one individual sees as important in a situation, another may not find very relevant or simply see in a totally different way – this has a background in cultural differences.
- Projection – an attitude, feeling that is part of your own personality but not experienced as such; instead, it is attributed to another person and then experienced as directed towards yourself by them rather than the other way round. This is especially important to be aware of when working in a foreign country, as many engineers do.
- Manner of speaking: "I, you, one, we." Different languages have different ways of expression.
- Deflection – Turn focus away from the conversation, a way to avoid direct contact with another person. An exercise with deflection is described later.
- Retroreflection – when we are not saying what we really think and feel but restrain our reactions, in everyday speech called self-control, self-command. Good to know when and why you do it, especially when working in a culture that is different from your own.
- Introjections – important for the learning of norms, e.g. you should not cross the street on a red traffic signal. But when working in another country there may be some customs that one does not want to embrace, e.g. a Muslim working in Denmark, where alcohol is a common part of a Friday afternoon get-together before the weekend.
- Networking – the importance of networking and trying to be more open to other people. How you develop your network and expand it further. Description of different kinds of electronic networks and how to behave and keep in contact in the long run.

INTERNATIONAL COMMUNICATION COURSES – ICC

The advantage of conducting the International Communication Courses (ICC) in a concentrated form is that it is possible to focus on using sufficient time on the communication part the way it is done in Finland.

When the International Communication Course has been given in Finland and Spain [11], it has been found that the students would rather do a large number of exercises, while the theoretical explanation of the topic should have limited scope to allow more time for exercises. In this way the students will gain progressive access to the subject and can be expected to have maximum concentration while the teachers only speak for about seven minutes at a time.

In our experience the students seem very positive and even delighted to attend the communication course, although some Finnish male IT students may have a negative approach to the way the course is run with regard to the exercises they are expected to actively engage in. They tend to have an attitude that the course is to no avail and that they will not learn anything from it; some also think they already know it all and therefore are reluctant to engage actively in the tasks. They appear to have learned something using their brains, but not their bodies, e.g. by taking part in interactive exercises, which is not integrated knowledge. It demands a great effort by some of the Finnish male IT students to get motivated and understand the importance of a communication course like this. We also experienced that some of these students found the exercises childish. In February 2011 we noted that the Finnish male students had a tendency to bunch together wanting to be in the same group. We grew very careful to divide the Finnish students in such a fashion that during the exercises a non-Finnish student was paired with a Finnish student – it appeared to be very important in order to achieve a good result. This issue will be a matter of great attention at upcoming communication courses.



Figure 2, Helsinki Metropolia University of Applied Sciences, Finland

The Nordic countries are located far up in the north from latitude 54:35N to 71:12N and the difference in the amount of daylight between summer and winter is very significant. This has a great influence on people's moods and communication capability/inclination. This is very obvious when for example Spanish, Portuguese and Italian students stay at DTU in Denmark as they have great problems coping with the lacking daylight/sun in the wintertime. In Narvik, in northern Norway, where J.E. Christensen worked for some years, it was evident that people who were not born there had great problems in dealing with the dark winter. In Narvik the sun cannot be seen from 7 November to 7 February as the mountaintops cut off part of the light apart from the sun being very low in the horizon. Helsinki, the capital of Finland, located at 60:10N has much more daylight in August than in February. This, concurrent with

app. 1 m of snow and -17 C° , had an influence on the course, the mood and the energy to get involved with foreign students – and thus the evaluation questionnaire of February 2011. The Finnish students, when asked about this matter, described their personalities as gloomy and introvert allegedly due to the harsh history and background of their ancestors. Finland fought a gruesome war with the Soviet Union and there has also been a history of landowners exploiting tenant farmers.

It deserves notice that in August 2010 there were only three Finnish students out of 19 present, whereas in February 2011 the attendance of the Finns was app. 50% out of 15. Comparing these two courses, it is also important to be aware of the fact that the number of students is relatively small for a statistical analysis, and consequently, the responses of individual students will have a great weight on the result.

QUESTIONNAIRE – INTERNATIONAL COMMUNICATION COURSE

The paper questionnaire was drawn up as a two-page inquiry form with nine questions on the front page and possibilities for individual comments on the reverse side of the page. The answers were ranked from very much / very important (positive) (1) to very little / not important (negative) (5) to simplify the students' answers and to make it possible to quantify them. As a consequence of former questionnaires with too many questions, resulting in missing or unserious responses, it was considered important to simplify the inquiry form. In addition to the inquiry form, it is our intention that students, who have attended the course 6-12 months earlier, will be selected for personal interviews in order to gain more detailed information about the CDIO evaluation.

International Communication course – Questionnaire

23-27th of August, 2010

Please answer the following questions by using your own words.

Rank the following questions on a scale from 1 to 5, where 1 is the "best / very much / very important" and 5 is the "poorest / very little / not important".

	1	2	3	4	5	
1. How much do you think you have learned in this course?						Very much
2. Do you think it is important to take a course like this in international communication?						
3. Will you be able to use what you have learned during this course?						
4. Does this course contribute to you being more friendly towards people from other countries?						
5. Would you like to have a follow up course, where you can improve and further develop your communications skills?						
6. Do you feel that your contact with your fellow students has improved?						
7. Do you think this course will help you to network better?						
8. Would you like to have more Finnish students to participate in the course?						
9. Will you recommend this course to your fellow students?						

- To what extent did this course make you conscious of the challenges of communication?

- Give an example of something valuable you have learned

- Did the exercises make you commit yourself?

- How is your benefit of the exercises?

- How do you think this course could be improved?

Figure 3. The two-page questionnaire in English, as it was distributed to the students. Front page on the left and reverse side on the right.

The two-page questionnaire is shown in figure 3. The front page of the questionnaire contains the questions specially designed for this course. In the next paragraph there is an interpretation of some of the questions.

The reverse side of the questionnaire contains, first of all, the possibility for the students to make personal comments – see figure 3 on the right. The following is the text of the reverse side of the two-page questionnaire:

Please answer the following questions by using your own words.

- To what extent did this course make you conscious of the challenges of communication?
- Give an example of something valuable you have learned.
- Did the exercises make you commit yourself?
- How did you benefit from the exercises?
- How do you think this course could be improved?

The simplified form of the questionnaire makes it easy and fast for the students to answer the evaluation questions.

ANALYSIS OF THE QUESTIONNAIRE

In the following is an interpretation of some of the questions of the questionnaires of August 2010 and February 2011. There were nine questions in all, of which six will be commented on in this section. The first four questions are dealing with the quality of the course and the last two with the communication between the students. The evaluation is based on 19 answers in August 2010 and 15 in February 2011.

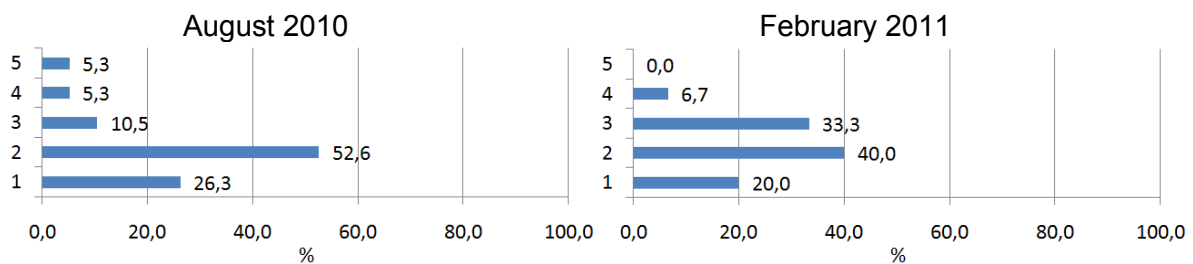


Figure 4. Results from question 1 – “How much do you think you have learned in this course?” The grades are ranked from very much (positive) (1) to very little (negative) (5)

1. “How much do you think you have learned in this course?” – See results in figure 4 – 78.9% respondents in 2010 and 60% in 2011 gave the grade 1 or 2, while 10.5% and, respectively, 33.3% gave the average grade 3. Only 10.6% and, respectively, 6.7%, gave the low grade 4 or 5. The results gained from this question indicate that the students feel they have greatly benefitted from the courses, since 91.4% on average rated them with grades ranging from medium to the highest.



Figure 5. Results from question 3 – “Will you be able to use what you have learned during this course?” The grades are ranked from very much (positive) (1) to very little (negative) (5)

3. “Will you be able to use what you have learned during this course?” – See results in figure 5 – 89.5% in 2010 and 80% in 2011 gave the grade 1 or 2, while 10.5% and respectively 20% gave the average grade 3 and nobody gave the low grade 4 or 5. The results gained from this question show that the students feel they will be able to use what they have learned since 100% gave a grade ranging from medium to the highest.

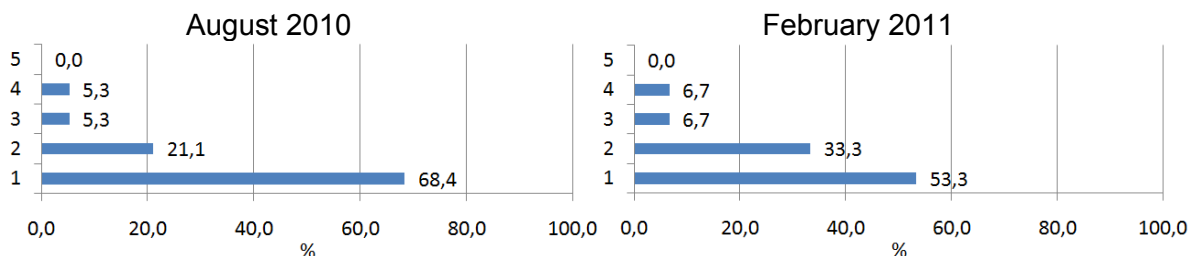


Figure 6. Results from question 5 – “Would you like to have a follow-up course where you can improve and further develop your communications skills?” The grades are ranked from very much (positive) (1) to very little (negative) (5)

5. “Would you like to have a follow up course, where you can improve and further develop your communications skills?” – See results in figure 6 – 89.5% respondents in 2010 and 86.6% in 2011 gave the grade 1 or 2, 10.6% and, respectively, 13.4% the average grade 3 or 4. Nobody gave the low grade 5. The results yielded by this question show that the students feel they would like to have a follow-up course since 94% on average of August 2010 and February 2011 respondents gave a grade ranging from medium to the highest.

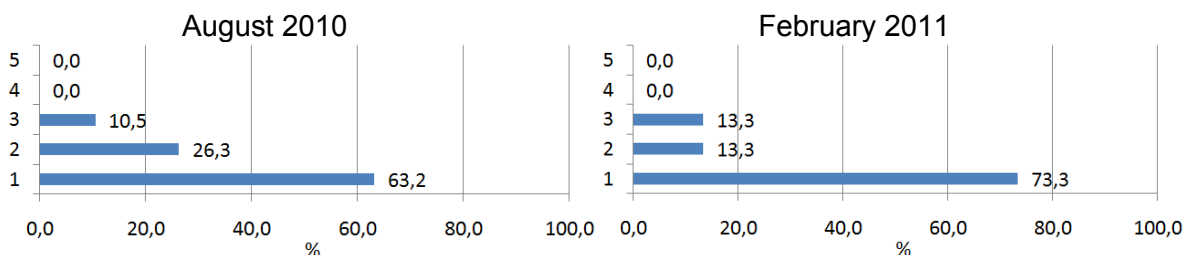


Figure 7. Results from question 9 – “Will you recommend this course to your fellow students?” The grades are ranked from very much (positive) (1) to very little (negative) (5).

9. “Will you recommend this course to your fellow students?” – See results in figure 7 – 89.5% respondents in 2010 and 86.6% in 2011 gave the grade 1 or 2, while 10.5% and, respectively, 13.3% gave the average grade 3 and nobody gave the low score 4 or 5. The results gained from this question show that the students feel they would like very much to recommend this course to their fellow students since 100% gave a grade ranging from medium to the highest.

Altogether, these four questions dealing with the quality of the course show a very high contentment with the course and the interactive education with personal involvement and exercises. The two highest grades of the answers to these four questions range from 69.5% to 88% (on a yearly basis). The positive answers indicate that the students are very satisfied with the course and that they recognise the need for education on international communication.

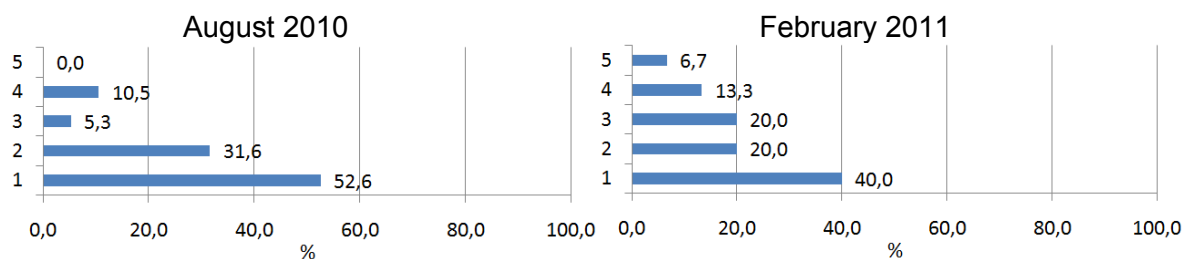


Figure 8. Results from question 4 – “Does this course contribute to you being friendlier towards people from other countries?” The grades are ranked from very much (positive) (1) to very little (negative) (5)

4. “Does this course contribute to you being friendlier towards people from other countries?” – See results in figure 8 – 84.2% respondents in 2010 and 60% in 2011 gave the grade 1 or 2, 5.3% and, respectively, 20% gave the average grade 3. 10.5% and, respectively, 20% gave the low grade 4 or 5. The results gained from this question indicate that the students get friendlier towards people from other countries.

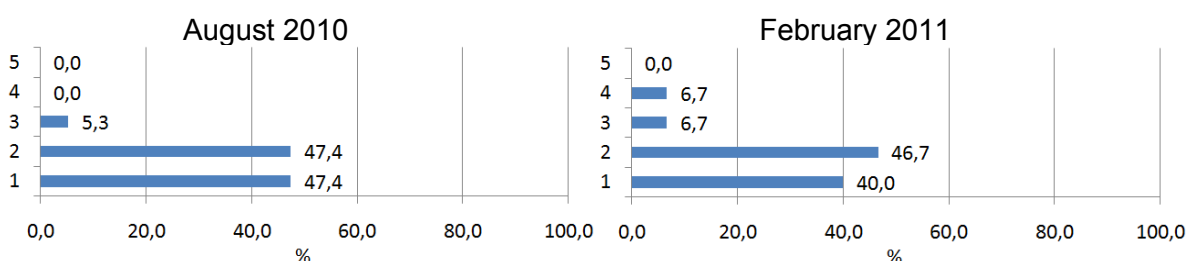


Figure 9. Results from question 6 – “Do you feel that your contact with your fellow students has improved?” Grades are ranked from very much (positive) (1) to very little (negative) (5)

6. “Do you feel that your contact with your fellow students has improved?” – See results in figure 9 – 94.8% respondents in 2010 and 86.7% in 2011 gave the grade 1 or 2. 5.3% and, respectively, 13.4% gave the score 3 or 4. Nobody gave the low score 5. The results gained from this question show that the students strongly feel that their contact with their fellow students has improved since 96.8% respondents on average of August 2010 and February 2011 gave a grade ranging from medium to the highest.

One of the goals of Metropolia is to enhance the communication skills between local (Finnish speaking) and international (English speaking) students. The two questions dealing with this issue show a very high contentment with the course and the possibilities given to students to communicate with each other. The two highest grades of the answers to these two questions rank on average from 72% to 91% (on a yearly basis). Thus it can be concluded that the idea behind the course seems to support Metropolia’s aim.

Questionnaire – individual personal comments

The reverse side of the questionnaire contains the possibility for the students to make personal comments. There are five questions for the students. The following is a selection of some answers from the students (shown as written in the questionnaire).

To what extent did this course make you conscious of the challenges of communication?

August 2010:

- “Very much, we learned different ways, styles, and developed our communication skills very much during this course”.
- “It was great to have people all around the world and try to overcome the challenge of misunderstanding someone because of his/her lack of language skills or cultural differences”.
- “It made me conscious of some communication problems I could face in the future and day to day life”.
- “Now, I can notice some small but important factors for communication that I didn’t know before. Also I learned how to behave and talk well when I communicate with other people”.
- “The different ways of communicating and be aware of the small details such as body language”.
- “Basically this course helped me personally to be more conscious with different situations –International Communication Course helped to develop more awareness in public speaking etc.”

February 2011

- “Communicating and performing have always been a struggle to IT-students”
- “This course helped me to improve the communication power, how to deal with other people from other countries and in what ways”
- “I realised the meaning of body language and how much it can affect people”
- “I had the general knowledge before the course but hopefully now I can actually use it, now that I have seen what all of this actually meant”.
- “I realised that I really do need these skills, because of the examples of trying to get a job”.
- “The course really awakened my practical aspect of communication. I am now confident of starting a talk and continuing it”.

Give an example of something valuable you have learned.

August 2010

- “How to communicate with people politely, how to react listening to my feeling inside, accept that other cultures are different.”
- “Noticing my own reactions and feelings in different situations”.
- “You have to accept people as they are. Everyone has a different background, so everyone reacts different to every situation”.
- “I have learned how to interact and adapt to people from other countries”.
- “Being able to communicate without thinking of barriers has helped me to learn more about other cultural behavior and expectations. It has also helped me to know that people are very nice if you use the right approach to interact with them”.

February 2011

- “Professional way of conversation with new people”.
- “How people behave in conversations or in relation to certain circumstances. For example introjections, projection, deflection and many other abstract behaviors”.
- “Body language’s importance in communication”
- “Controlling my body language better and my “small talk” as well”.
- “Importance of body language and what kind of reactions you should look for in the others”

Did the exercises make you commit yourself?

August 2010

- “Yes. I felt the exercises were really fun, especially the ones where somebody was complementing you. It gave a nice feeling”.
- “Exercise actually helped a lot and showed us a way practically”.
- “Yes! By making me behave well, and respond or react to different situations without having to offend others”.
- “Yes all exercises were interesting and each of them has a conclusion that I understand”.
- “Yes, I had to wake up early and be in class on time”.

February 2011

- “Yes, as you know “practise makes man perfect””.
- “If the partner(s) was taking the exercise seriously also”.
- “Yes, it was fun”.
- “Yes a lot. I realised many things that I wasn’t aware before”.
- “I had to commit myself thanks to crowd activeness”.

How is your benefit of the exercises?

August 2010

- “I think I’ll notice the reactions of myself and others better. That’s a benefit”.
- “I can realize some of my abilities and know how to use them”.
- “I’m running a lot of courses so it’s important to remember that people are different and it is important to make everyone feel special and a part of the group”.
- “Exercises will be memorized easier than theory. Also, nice to practice certain social situations”.
- “To implement the learned skills in our daily life because communication skills are required in each and every step of our life and also in working life in companies”.

February 2011

- “The exercise that I have done during the lesson helped me how to change theoretical things into practice”.
- “I learned a lot about myself. It sure will help me in the future”.
- “I learned to cope with other people better and understand them better”.
- “I think those exercises improved me mentally a lot”.
- “Makes me practice to talk, behave with people and teach me to be a good listener as well”.

How do you think this course could be improved?

August 2010

- “It would have been better to do the exercises in open and bigger area”.
- “The body language aspect could be explored more deeply. Also not so many optical illusions. Jørgen could sometimes stick more to the point when talking long. It’s okay to go off-topic, but sometimes it was too much”.
- “Just by adding more interesting games or examples, or having an extra teacher who could”.
- “I think one week is not enough, two weeks should be very nice”.
- “I think this course should have more practical exercises”.

February 2011

- “I don’t think it could be better. Needs more time to do all these exercises”.
- “Different themes should be introduced better; tell what they are about. Then rehearse/practise them. At some points I lost focus of what’s happening”.

- “More talking between students”.
- “Yes! Slow down in the first day. I was very scared and thought that I didn’t want to come here again. Fortunately I did, and the next day was easier”.
- “I think it’s pretty good the way it is. We discussed if it would be better to divide the lessons into two weeks but I think one week intensive course supports the course better”.
- “For the future, this course should be a compulsory subject and include so many students from different nationality”.



Figure 10. Students doing one of the exercises.

ICC – EXERCISE EXAMPLES

Example of an exercise from ICC – Deflection

Since the students referred to in this paper are IT students, comments shall be made specifically on an exercise that was found to be interesting for these students. The exercise is called “Deflection”. Person no. 1 (P1) tells an interesting story and person no. 2 (P2) is listening. In the beginning P2 is listening very intensely, making sure to show this. After three-four minutes P2 starts to deflect. In the beginning, P2 only deflects a little but gradually more and more. To deflect means that you are no more focused on the story but you are looking everywhere else than at P1. You may be checking your text messages or your watch – you may be paying attention to a conversation next to you. You are present in the actual situation but your mind is elsewhere. When doing the exercise with deflection, we have experienced that Asians and especially the Nepalese have a tendency to be too polite and therefore cannot do the exercise accurately – they listen and ask too much. We have seen analogous behaviour with students from Slovakia and Latvia. These communities have difficulties being impolite, whereas people from the Nordic countries are far better in this respect.

Another issue about the deflection exercise is when P1 is telling a very exciting story, thus making it is difficult for P2 to deflect. For example, a student told a very moving story about his fight with cancer, about how to survive and make it through the whole process of not knowing how it would end. It was extremely difficult for P2 to partly deflect because the story was interesting, but also because it would have appeared cruel to deflect on such an emotional story.

In the following are given two examples of deflection from real life. A person was at a job interview and three persons from the company were present, two of whom were listening

very carefully, whereas the third person was very unfocused and deflecting. This was most uncomfortable and appeared very rejecting, it being a job interview. Another example: On mentioning to some people that we work with IT students, one of our friends told us this: *“After finishing a project, a partner contacted me wanting a two-hour work-related meeting in order to discuss some issues. Perceiving that most subjects were fine, I thought this meeting would not be necessary and as I had a very busy schedule, I stated that we had to make it a very brief meeting. Shortly after the start of the meeting his phone rang and he talked for a long while. Later his phone rang again and once more he had a lengthy conversation. When we had talked for about 45 minutes he suddenly turned to his computer. He turned his back to me when he started working on it. I got very annoyed because I was rather stressed. I asked him if our meeting was over and he said “yes”, still working at his computer with his back turned towards me. This is how the meeting ended”.*

Several of our Finnish male IT students have pointed out that it is rather normal for them that, when together, each of them is occupied with their own thing while they “communicate” with each other. In some ways they have developed different norms of communicational behaviour, which they apply when having company. Since it is normal to them, they do not at all understand that they appear rejecting and non-present. The previous example was just about an IT person and his behaviour in a job related situation.

Final exercise from ICC – American Jazz Musician

On the last day of the course in August 2010 we gave the students an exercise about an American jazz musician in Denmark. In this exercise the students were to apply the theoretical mechanisms they had learned during the course and it turned out that the students had a great understanding of and insight into communication mechanisms they had newly been taught. However, when the students got the same exercise in February 2011, they were not able to solve the task at all as well as the group of August 2010. This exercise could be seen as a test not only for the students but indeed for us as teachers also, and thus we have to state that we weren't quite as successful in February 2011. This could have been due to our spending relatively more time on talking in general and not spending quite as much time on the specific exercises with matching theory. Experience from August 2010 and February 2011 together with three 2-hour courses in Alcalá give a clear indication that we have to confine ourselves to relatively short interpretations of theory or cases, which should only last about seven minutes. We have to focus much more on doing many exercises the students are actively engaged in – preferably several times so that the students really understand the fundamental theory and are able to put theory into practice in actual situations.

SEPARATE COURSES VS INTEGRATED COURSES IN ICC

There may be arguments arising against having the communication course as a separate course as well as integrated in a technical course. It is a question of the existing possibilities at the educational establishment concerned. At DTU Civil Engineering it will be very difficult to establish a separate course in communication (explained in more detail later); but at Metropolia they lay much weight on management and finances in their education, and they already established an ICT week in February. In addition, Metropolia has a summer school providing much better possibilities to hire lecturers from other universities and to experiment with and further develop the education programmes. Owing to summer school activities, courses can be adapted from year to year according to possibilities and wishes. Summer schools are therefore a valuable addition to an educational establishment.

Conducting the International Communication Courses (ICC) in a concentrated form and as separate courses has the advantage that it is possible to focus on using sufficient time on the

communication part, the way it is done in Finland. The duration of the course is one week and it is all about communication – the students have to work and commit themselves 100%, which is hard for many of them, and it is evident that a large number of the young people get very tired after the daily four hours of intensive work since they are obtaining new ways to experience the world and have to use their minds in completely different manners. It is our experience that the students are quite capable of letting go of the technology and turn their focus to communication, but if the communication course is related to a subject area that they are very interested in (like IT), they somehow do not let their minds off the technology nor turn their full attention toward communication [11]. Many of them have some difficulty with communication as such, so even if they really liked to work with communication, it is so much easier to resort to a subject area that they love to work on and know they are good at.

The semester at DTU consists of a 13-week period prescribed for courses of a total of 25 ECTS points (European Credit Transfer and Accumulation System), a two-week exam period and a three-week period prescribed for a one 5 ECTS points course, which is usually a more practical course with parts of the theory from the 13-week period put into practice. At DTU one 5 ECTS points course is equivalent of 13 weeks' input of an estimated workload of 9 hours/week with an estimated total workload for the full course at 117 hours. Normally the students have 4 hours of teaching and 5 hours of preparation for a course per week, translating into 52 hours teaching and 65 hours homework. The communication part will easily occupy 20 hours out of the 52 hours teaching time, which makes it harder to integrate the communication training into a normal course in the 13-week period. It will be easier to include the communication part in the 3-week 5 ECTS points course, where the students usually have no homework. However, they are expected to work for 8 hours a day during the course. Thus it will be much more suitable to include communication in the course, since it will only take up part of the time as the students are expected to be present for all 117 hours.

However, it could be a possibility to include a 4-hour icebreaking part in the first CDIO course during the first semester at the Department of Civil Engineering, where CDIO is introduced as a Design Build course. A student who studied the material from Metropolia stated that it could be helpful to have a similar course at DTU Civil engineering: *“Especially in the process of getting to know your new fellow students – there is a lack of courses at DTU that can support these areas (like the course at Metropolia)”*. The icebreaking part could be included in the first or second teaching block. Nevertheless, it will not be possible to include the whole communication course in the 5 ECTS points Design Build course since it will take up too much time from the whole course.

If we make the course a compulsory course, we will get students who are not really interested and only take it because they are obliged to do so, and this will weaken the outcome for the other students, since many of the exercises are done as pair work.

CONCLUSION

In many technical universities there is a lack of focus on teaching interpersonal skills such as ethics, communication, co-operation, commitment, leadership and teamwork. It is important that space is created in the curriculum for courses in the softer values. For some of the courses it should be a deliberate requirement, stated as a learning objective that the students will be evaluated on their interpersonal skills mentioned before. Thus they would feel urged to focus on their personal development knowing it is a part of the evaluation procedure.

Teaching softer skills can take place in strictly non-engineering courses on communication and interpersonal skills or in courses with a technical substance [11]. This paper presents the results from a strictly non-engineering course in communication. The duration of the course was a full week and it consisted of various small exercises with personal involvement,

whereby the participants could develop their interpersonal communications skills in the contact process. Experience shows that the students appear to be very positive and delighted to attend the communication course although a couple of Finnish male IT students had a negative approach to the way the course was conducted. Based on this it is our challenge to persuade such students of the importance of improving their communication skills. One of the reasons for this is that many of the exercises are done in pairs, and if a participant is negative, it can wholly or partly destroy the learning outcome for the other party. One way to solve this and achieve a good result was to place Finnish students together with non-Finnish students during these exercises.

In the questionnaire four of the questions dealt with the quality of the course. The results showed a very high satisfaction with the course and the interactive education with personal involvement and exercises. The grades one and two (1 best/very much, 5 worst/very little) of the responses to these four questions are ranging on average from 69.5% to 88% (on a yearly basis). The positive answers indicate that the students are very satisfied with the course and that they recognise the need for education on international communication.

The objective for Metropolia is to enhance communication skills between local (Finnish speaking) and international (English speaking) students. Two of the questions in the questionnaire dealt with this issue, and showed a very high satisfaction with the course and the given possibilities to communicate with fellow students. The grades one and two (1 best/very much) of the responses to these two questions range from 72% to 91% (on a yearly basis). Thus it can be concluded that the idea behind the course seems to support Metropolia's aim.

The course can be improved by reducing the teaching sessions to seven concentrated minutes between the exercises. This will give more time for exercises and revision. Currently 100% attendance of courses is required at Metropolia; however, in future courses participants will also be required to commit themselves through personal involvement rather than just being physically present.

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Biographical Information

Jørgen Erik Christensen received his M.Sc. and Ph.D. degrees from the Technical University of Denmark in Copenhagen, Denmark in 1981 and 1987, respectively. From 1988 to 1991, he worked at the Danish Building Research Institute, Denmark, and was in 1990 appointed to senior researcher. From 1992, he worked as Professor of Integrated Building Technology at Narvik University College, Norway. From 1994 – 1995, he worked as Managing director at Narvik – Peace Centre in the North. From 1997 to 2001 he studied gestalt therapy specialising in communication at the Norwegian Institute for Gestalt. From 2003 to 2007 he was an Associate Professor at the Faculty of Engineering, Oslo University College and completed a Fundamental Course in Education for College Lecturers during 2004-2005. From 2007 until present he has worked as an Associate Professor with the Department of Civil Engineering, Technical University of Denmark. In 2009 he studied “Pedagogical and Didactic Theory about University Education and Teaching” at the Danish Pedagogical University, Denmark. He has been involved in national and international research in the field of energy and environment and is a co-developer of an internationally used thermal analysis program known as tsbi3. Dr Christensen is a member of the CDIO implementation board of the Department of Civil Engineering at the Technical University of Denmark.

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Cecillia Christensen received her degree as Interior Decorator in 1975. She has completed various courses in personal development and in 2002 was awarded her degree as NLP Practitioner.

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CURRICULUM INTEGRATION: TWINNING OF A CORE CHEMICAL ENGINEERING MODULE WITH A TEAMWORK & COMMUNICATION MODULE

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ABSTRACT

Teaching in the Diploma in Chemical Engineering (DCHE) of Singapore Polytechnic largely follows the traditional way of covering various technical disciplines in modular format, taught by faculty with relevant working experience in the chemical and process industries. The teaching is supported by various “soft skills” such as inter-personal communication, report writing and presentation taught separately by faculty from the School of Communication, Arts and Social Sciences (CASS).

Since its adoption of CDIO in 2007, the DCHE Course Management Team (CMT) had directed its efforts at integrating various CDIO skills into suitable core modules in the curriculum. One such module is *Introduction to Chemical Thermodynamics*, taught to Year 1 students where CDIO skills such as teamwork and communication, personal skills and attitudes (e.g. critical and creative thinking) had been integrated. Subsequent evaluation of the module had shown that, although students generally benefitted in learning about CDIO skills in the module, there is a strong need to further integrate the module with key concepts underpinning teamwork and communication. As a result, the various “soft skills” modules are consolidated into a new module entitled *Teamwork and Communication Toolbox*, to be taught in such a way that it “twins” with the CDIO-infused *Introduction to Chemical Thermodynamics* module.

The CMT works closely with CASS in designing the syllabus and learning outcomes for the *Teamwork and Communication Toolbox* module. CASS faculty retains the responsibility for teaching the *Teamwork and Communication Toolbox* module, while DCHE faculty handles the teaching of the *Introduction to Chemical Thermodynamics* module. Student learning is achieved via carefully designed “twinning” activities that requires them to integrate the knowledge gained in both modules.

The paper shares the work done in the “twinning” initiative (including active learning experiences) and compares the impact on student learning before and after the “twinning”. The challenges faced, and future recommendations to further improve the “twinning” process will also be discussed.

(NOTE: Singapore Polytechnic uses the word "course" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called “courses”.)

KEYWORDS – Curriculum integration, twinning, chemical engineering, CDIO skills, program evaluation

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) course in Singapore Polytechnic is one of the 49 courses available to students. The teaching is largely modular in nature, whereby students are required to complete a suite of up to 6 modules each semester, over 6 semesters in a 3-year period. Such modular teaching can result in compartmentalization of knowledge by students, unless the faculty actively make a conscious effort to integrate the various chemical engineering disciplines.

Curriculum integration is therefore of utmost importance in linking together the various knowledge and skill components taught in these separate subject modules. This is clearly captured in CDIO Standard 3 “Integrated Curriculum” which stated that a curriculum should be “designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process and system building skills.” (Crawley, et al, p.35 [1]).

DCHE had adopted CDIO as the basis of revamping its curriculum since 2007 (Cheah [2]), and had integrated specific CDIO skills into its various core modules. The emphasis of the integration effort is mainly directed at creating active learning experiences for students in practicing CDIO skills. However, due to an already-packed curriculum, there had been little opportunity to adequately cover the underpinning knowledge of the CDIO skills in the core modules. Hence, the teaching of these “soft skills” is still covered in separate standalone modules, and taught by faculty from the School of Communication, Arts and Social Sciences (CASS).

This paper presents an initiative by the DCHE Course Management Team (CMT) to further strengthen the curriculum integration effort by “twinning” a core chemical engineering entitled CP5067 *Introduction to Chemical Thermodynamics* and a “soft skill” module entitled LC0236 *Teamwork and Communication Toolbox*. Both modules are offered to Year 1 students in the same semester of study.

DESCRIPTION OF WORK DONE

This section will firstly outline the learning designs for *Introduction to Chemical Thermodynamics*, a Year 1 core chemical engineering module; before the “twinning” initiative that require students to practice CDIO skills. It then discusses the results of a student survey that, although confirming the usefulness of active learning, also highlighted concerns among students that they needed more understanding of the key concepts underlying teamwork and communication. This is followed by a discussion of the “twinning” initiative and explanations on modifications made to improve student learning. Lastly, a new survey result is presented, which compares the impact on student learning of such “twinning” mode of teaching.

Active Learning Activities

The curriculum re-design effort followed the “standard” approach taken by the DCHE CMT as outlined by Sale and Cheah [3], Cheah [4], and Cheah and Sale [5]. and Drawing on the requirements as spelt out in CDIO Standard 8 “Active Learning”, we used the student-centred approach to curriculum design by Felder and Brent [6] (see Figure 1) to introduce various CDIO skills into the module.

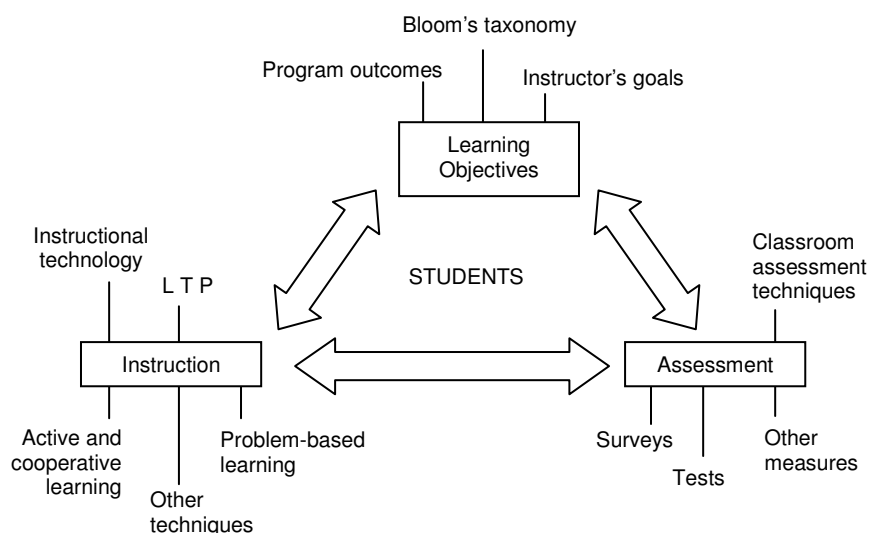


Figure 1. Student-centred approach to curriculum design

The basis for the approach in designing active learning activities for the module is derived from extensive research that students learn best when they perceived a clear need to know the material being taught (Felder [7]). It is also clear that the best opportunity lies not in the classroom but in the laboratory, where students work in small teams. Hence, all five laboratory activities of the module were designed using real-world work scenarios that contextualize the learning environment so that students can experience the needs to master the various CDIO soft skills. Emphasis is placed on three selected CDIO skills of teamwork, communication and personal skills and attitudes (focusing namely on thinking, and managing learning).

Table 1 shows the laboratory sessions for the module *Introduction to Chemical Thermodynamics* and the selected CDIO skills covered.

Table 1.
Selected CDIO skills infused into each activity

Activity S/N and Name	CDIO Skill Infused			
	Teamwork	Com- munication	Thinking Process	Manage Learning
1. Size Analysis & Energy Requirement in Grinding	√		√	√
2. Study of Gas PVT Relationship		√	√	√
3. Thermodynamics of Steady-State Flow System			√	
4. Energy Efficiency of a Fuel Cell			√	√
5. Study of Vapour-Liquid Equilibrium for a Binary Mixture	√	√		√

The underpinning knowledge of these CDIO skills is made available in the laboratory manual, which also contains detailed descriptions for each activity. The instruction for each laboratory activity is divided into several sections, i.e. learning objectives, theory, pre-experiment assessment, conduct of experiment, post-experiment assessment, results and calculations, discussion, and/or independent learning.

For example, in Activity 1 “Size Analysis & Energy Requirement in Grinding”, students are required to analyze the task to be performed and divide key task components to team members. The basis of task allocation and impact of the role on team performance must be justified and presented to the faculty-in-charge. The activity helps students to demonstrate teamwork skill through the practice of job delegation in order to perform a group work effectively.

Both written and oral communication skill are infused in all laboratory activities through report writing and presentation of answers orally during in-class assessment. However, communication skill is particularly emphasized in two activities. Students are tasked as an assistant engineer in a chemical company in Activity 5. Given a work scenario to conduct training on “distillation principles” to a group of plant operators, students are required to practice their oral communication skill in a technical context.

Other CDIO skills such as “Apply Thinking Process” and “Manage Learning” are also embedded into the laboratory activities.

As the module is taught to students in the first semester in their first year of study, most if not all of them, had barely knew each other, and have little understanding of what constituted CDIO skills. The grouping for laboratory activity was done by the faculty in an arbitrary manner. A briefing was conducted in the first week of the semester, prior to the commencement of the laboratory in the following week. The purpose is to explain the underpinning knowledge of the CDIO skills, in particular the key components and attributes of a successful team. Students were asked to discuss with their assigned team members and complete a “Pre-Experiment Exercise”. In this exercise, students are required to identify the strengths and weaknesses of each team member, goal of the team, situations whereby failure of a member can adversely affect the team performance, and set ground rules for the team. A sample worksheet for the “Pre-Experiment Exercise” is shown in Appendix 1.

The laboratory activities were conducted on a twice-weekly basis. Each week, one group of students will work on one activity, taking turns on a rotation basis, to work on another activity two weeks later. This continues for the entire semester (15 weeks) until all activities are completed. During the conduct of the laboratory sessions, one faculty served as facilitator and assessor for the entire 3-hour duration of each activity. An additional faculty served as a first-hour assistance to the faculty, so that all five groups can start-off on their tasks as soon as possible, i.e. by meeting all the requirements of the Pre-Experiment Assessment (detailed in following sections).

Assessment

Assessment is perhaps the most powerful curriculum component in terms of shaping student’s approaches to their learning (Edstrom et al, [8]). In fact, Ramsden [9] points out that:

from our students’ point of view, assessment always defines the actual curriculum Assessment sends messages about the standard and amount of work required, and what aspects of the syllabus are most important. (pp.187-188)

Detailed planning went into the design of assessment questions in these laboratory activities. A customized assessment scheme is prepared for each activity. Detailed breakdown for each assessment scheme is provided in the instruction manual. A sample of this is shown in Figure 2.

The assessment can be broadly classified as In-Class Assessment and Report Assessment. The In-Class Assessments were carried out at two key points in time: first at the beginning of

class (the so-called “Pre-Experiment Assessment” and later during debrief at the end of class – “Post Experiment Assessment”. Students were also assessment on their overall conduct of the experiment. The pre-experiment assessments are introduced to test students’ understanding prior to allowing them to start the experiment. Students are encouraged to practice teamwork by preparing for each activity before the actual date of the activity. During such preparation work, students need to learn how to manage their own learning, as certain topics may yet to be taught in class at the time of the activity in the laboratory.

	ASSESSMENT SCHEME	Weightage	Individual	Group
In-Class Assessment				
I	Pre-Experiment Assessment			
	A. Understanding Theory Hazard Identification and Safety Precaution	25%	√	
II	Conduct of Experiment			
	A. Punctuality and Display of Positive Learning Attitude	5%	√	
	B. Safety Practice and Housekeeping	5%	√	
III	Post-Experiment Assessment			
	A. Questions for Practical	10%	√	√
Report Assessment				
	A. Results and Calculations	13%		√
	B. Discussions	17%		√
	C. Independent Learning	15%		√
	D. References	5%		√
	E. Overall Presentation	5%		√
	TOTAL MARKS	100%		
	Penalty for Lateness (-5% / day)			

Figure 2. Sample Assessment Scheme for Laboratory Activity

On the other hand, the aim of post-experiment assessments can be broader. In addition to testing students on their observations of the conduct of the activity, they may be assessed on other knowledge and skill areas, depending on the specific learning outcomes of each activity. This may include understanding the rationale of the way the steps are sequenced, testing of hypotheses formulated by students, etc. Questions were also designed for students to integrate what they learnt in other modules such as *Introduction to Chemical Engineering*; into what they learnt in this module; for example, unit conversion and unit consistency when performing engineering calculations.

Students are given two weeks to submit a group written report. Guidelines for report writing are communicated to students during the briefing. A wrap-up session on all the laboratory activities is conducted at the end of the semester to give overall feedback on the report and to highlight the common mistakes made, as well as clarify any doubts over the technical concepts.

Program Evaluation: Obtaining Student Feedback

The methods utilised to collect the feedback from students on the effectiveness of the active learning activities embedded with CDIO skills are consistent with the approach adopted for DCHE [4]. We engage six students (two from each class) to serve as “co-participants” (Lincoln, [10]), who regularly blog regarding their learning experiences in an online journal. Students are typically presented with a range of questions relating to the learning tasks, and asked to provide specific examples to support their responses. These student co-participants

also took part in a focus group interview at the end of the semester. Both blogging and focus group discussion are facilitated by education advisors from the Department of Educational Development (EDU), in absence of faculty participation. We also used questionnaire for mass survey of all students, again at the end of the semester and administered by EDU staff.

Evaluation of Student Feedback (before “Twinning”)

In summary, a questionnaire was administered to all students taking the module at the end of semester. The total respondent is 57 out of 61 and the response rate was about 93%. Some of the notable findings are presented below.

Firstly, the results of student survey confirmed the usefulness of active learning in facilitating learning of the module, and showed high appreciation for the importance of teamwork and communication skills. However, students also expressed concern over the long waiting time for consultation with the faculty, especially after the departure of the first-hour assistant. The insufficient engagement and contact time with the group may cause difficulty in assessment of teamwork and other skills in each group. Some students suggested peer assessment for a fairer assessment on teamwork skill among group member.

Secondly, students also highlighted another concern that they had not learned communication skill in their first semester, hence faced difficulties in demonstrating effective communication skill, in both written and oral forms. Some were unable to see connections between the underpinning knowledge briefed earlier and the tasks they were asked to perform in a given activity.

Thirdly, students informed that they generally understand the characteristics of being a good thinker and agreed on the importance of having good thinking skill. However, they found some of the tasks challenging and expressed concern about their competency in using a range of critical and creative thinking skills to perform these tasks. They cited lack of knowledge on how to approach the thinking process and acquire the necessary thinking skill. Table 2 below summarizes students’ perception and the context of CDIO skill on “Good Thinking”.

Table 2.
Comparison of student perception and CDIO context of “Good Thinking”

Students’ perception on “Good Thinking”	CDIO context of “Good Thinking”
<ul style="list-style-type: none"> ▪ Have good foundations of knowledge ▪ Able to resolve problems ▪ Have innovative ideas and solutions ▪ Understand the questions posted ▪ Analysis what had learnt and use it logically and practically, and then create more methods for solutions 	<ul style="list-style-type: none"> ▪ Use ranges of critical thinking skills ▪ Use ranges of creative thinking tools and techniques ▪ Identify contradictory perspectives and underlying assumption ▪ Reframe and take a range of different perspectives ▪ Use meta-cognition in monitoring the quality of personal thinking

Faculty Personal Reflections and Review of Implementation

Overall, the main author (as the faculty teaching the module) generally found that students are motivated, coming to the laboratory sufficiently prepared and able to manage their learning more independently out of classroom. Facilitating the activities also helped deepen faculty understanding of the CDIO skills, leading to strong internalization, and build up faculty CDIO competency.

The author's shared students' concern of insufficient time for more engagement during these laboratory sessions. This is especially challenging during the last hour where the faculty had to conduct debriefs for all the five groups; performing a multitude of tasks which include reviewing the students' experimental data, conducting post-experiment assessment, etc.

Faculty also empathised with students' comments on lack on synchronization between the independent teachings of communication skills and technical subjects in the current arrangement. A case in point is the teaching of the module *Report Writing and Presentation*, which is only taught to Year 1 students in Semester 2. In addition, the faculty also realised that teamwork need to be explicitly taught to students. There is insufficient time during the first-week briefing for more in-depth exercises to adequately prepare students for applying teamwork skills. These factors points to a strong need to align the teaching of soft skills and teamwork, and served as strong motivation to revise the DCHE Year 1 course structure.

The explicit development of thinking skills is another area which needs further faculty development. This is presently being addressed; the approach and results are presented in a separate paper [11].

Improvement Made: The "Twinning" Initiative

Several improvements were made on the module after incorporating students' feedback and the faculty's self-reflection and review. A major recommendation that was adopted by the CMT is to introduce a new module entitled *Teamwork and Communication Toolbox* to support student learning of these core CDIO skills. The new module is created by merging and streamlining two existing modules: *Report Writing and Presentation* (as mentioned previously), and a Year 2 module *Effective Interpersonal Communication*. Overlapping topics and contents were rationalized to allow the introduction of topics on teamwork. The new module hence provides a platform for students to learn both teamwork and communication skills (oral and written) in a more structured and systematic approach. A sample of learning objectives is provided in Figure 3.

S/N	<u>Learning Outcomes</u>
A	TEAMWORK AND INTERPERSONAL COMMUNICATION
1	Understand What Makes an Effective Team
1.1	Identify components of an effective team.
1.2	Explain team roles and their impact on team performance.
1.3	Analyse the strengths and weaknesses of a team.
2	Understand the Relationship Between Teamwork and Communication
2.1	Identify types of verbal and non-verbal communication.
2.2	State causes of verbal and non-verbal miscommunication.
2.3	Explain how verbal and/or non-verbal communication affects teamwork.
C	ORAL COMMUNICATION
7	Understand the Basic Principles of Oral Presentation
7.1	Define the purpose, the audience and the context (PAC) of a presentation
7.2	Identify the essential elements (verbal and non-verbal) of a good presentation
7.3	State the delivery strategies for an effective oral presentation
8	Prepare for the Presentation
8.1	Plan the speech by determining the audience, purpose and context (PAC) required
8.2	Decide on a presentation strategy for the team
8.3	Select suitable delivery strategies for the presentation
8.4	Select appropriate visuals e.g. PPT slides for the presentation
8.5	Anticipate questions and prepare answers for the Q & A

Figure 3. Sample learning objectives in *Teamwork and Communication Toolbox*

Also, by introducing *Teamwork and Communication Toolbox* in first semester, together with *Introduction to Chemical Thermodynamics* in the same semester, we can proceed with our “Twinning” effort that allows students to simultaneously learn and apply teamwork and communication skills in a relevant chemical engineering context.

The key feature of twinning the two modules is to align the learning activities and assessments in both modules. The authors (from DCHE) worked closely with CASS faculty to redesign the learning activities in the *Introduction to Chemical Thermodynamics* module which also serves as assignments in the *Teamwork and Communication Toolbox* module. In that way, students are taught and assessed for both technical and soft skills in a coordinated manner. In addition, the role of the first-hour helper has now been converted to a full three-hour support.

As an example, students are given a real-world work scenario in which they need to conduct a training lesson in distillation principles to a group of plant operators using PowerPoint. In this activity, the CASS faculty will focus on teaching oral presentation skill, providing guidance in presentation slides preparation and delivery of group presentation. On the other hand, the DCHE faculty (i.e. the main author) provides guidance on technical contents of the presentation. Both faculty then jointly assess the students on their competency in both the technical domain and CDIO skills. The same practice applies to written communication skill when students are required to submit a scientific report using one of the laboratory activities to both faculty. Figure 4 shows the workflow of the integrated assessment in scientific report writing.

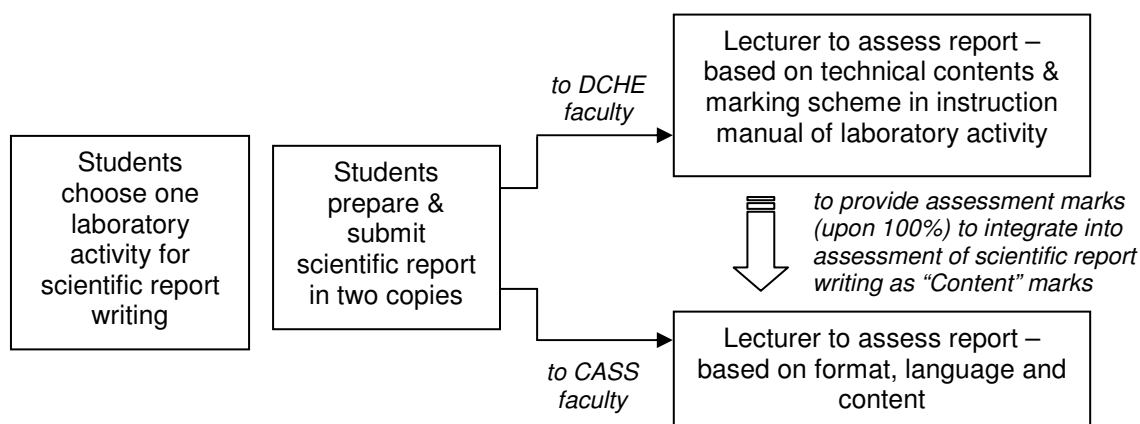


Figure 4. Workflow for integrated assessment in scientific report writing under the Twinning Initiative

Faculty from both CASS and DCHE also decided to improve the “Pre-Experiment Exercise” on teamwork mentioned previously, in order to sustain the development of students’ teamwork skill throughout the semester. This is achieved via the introduction of a reflection component on the “Pre-Experiment Exercise” during mid-semester, which serves as a mid-point check. In this group reflection exercise, students review their strengths and weaknesses, team’s goals, ground rules and performance that are stated in the “Pre-Experiment Exercise”. If required, students can make changes to their ground rules in order to achieve the team goals.

At the end of the semester, a “Team Effectiveness and Peer Evaluation Form” is administered to all students. Students will rate individual contributions as well as team performance; and record any conflicts that arose in the course of carrying out the activities for the module *Introduction to Chemical Thermodynamics*. The results of the peer assessment will serve as input of an assessment activity in the module *Teamwork and Communication Toolbox*.

Figure 5 shows the workflow of administering the integrated activities related to teamwork skill for both modules.

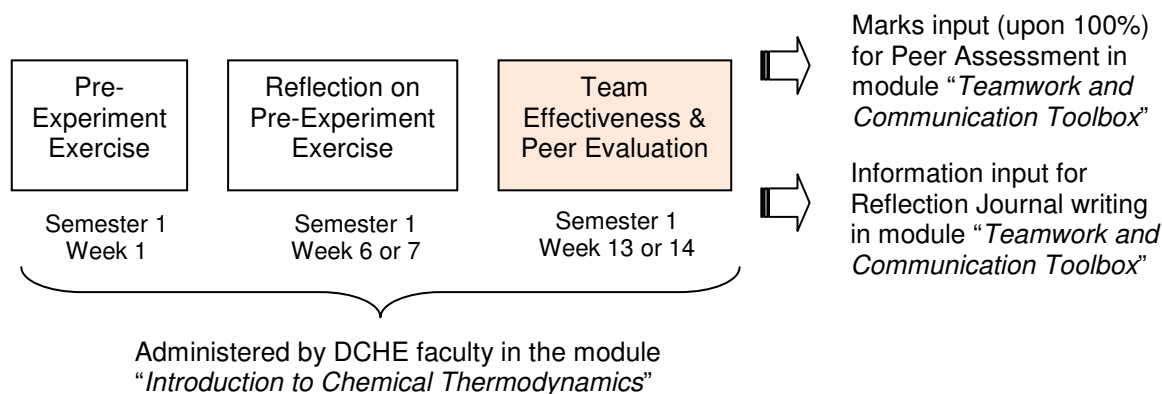


Figure 5. Administration workflow for integrated activities under the "Twinning" Initiative

Any real conflicts that may have arisen during the course of the semester, will be summarised by DCHE faculty and shared with the CASS faculty. The CASS faculty will use the findings as input to facilitate discussion of applying conflict resolution strategies teamwork and interpersonal communication.

Evaluation of Student Feedback (after "Twinning")

A new round of survey was conducted for students who have gone through an integrated learning activity, i.e. oral presentation and joint-assessment from both core chemical engineering module and teamwork and communication module. The total number of respondents is 60 (out of 63), giving a response rate of 95%.

Students are asked of their learning experience in activities that integrates assessment from both perspectives. Specifically, they are asked to indicate on a 4-point Likert Scale, the extent to which they agree disagree with the following statements (1 being Strongly Disagree and 4 being Strongly Agree):

Merits of Twinning on Learning Oral Presentation (see Figure 6 for responses)

- Q.1 *The twinning assignment allows me to have a better understanding of the importance of oral communication skill in the job scope of a technologist or an engineer.*
- Q.2 *With the twinning assignment, I am able to apply what I learnt in LC0236 to actual oral presentation in technical context, more so than if the two modules are taught and assessed independently.*
- Q.3 *With the twinning assignment, I am more mindful of the importance of both technical contents and delivery strategy for oral presentation.*

Joint-Assessment of Oral Presentation (see Figure 7 for responses)

- Q.1 *I feel comfortable for both lecturers from LC0236 and CP5067 to conduct the assessment of oral presentation due to their competency in different aspects.*
- Q.2 *It is appropriate and fair for CP5067 lecturer to assess the "content" of the oral presentation as the lecturer understands the technical content the most and gives better judgement on the contents, more so than the "content" is assessed by LC0236 lecturer.*

- Q.3 *It is appropriate and fair for both LC0236 and CP5067 lecturers to assess the “Management of Q&A” as they could have better judgement on the clarity and relevancy of the answers given by students respectively.*
- Q.4 *The feedback from LC0236 and CP5067 lecturers on my oral presentation gives me more ideas for improvement in both technical contents and oral communication skills.*
- Q.5 *I would prefer the co-assessment in twinning mode, i.e. by both LC0236 and CP5067 lecturers, more so than the assessment is done independently in two modules.*

The result from this survey is very positive; with more than 90% of the students indicating preference for the “twinning mode” of teaching; as compared to learning technical and soft skills in separate standalone modules.

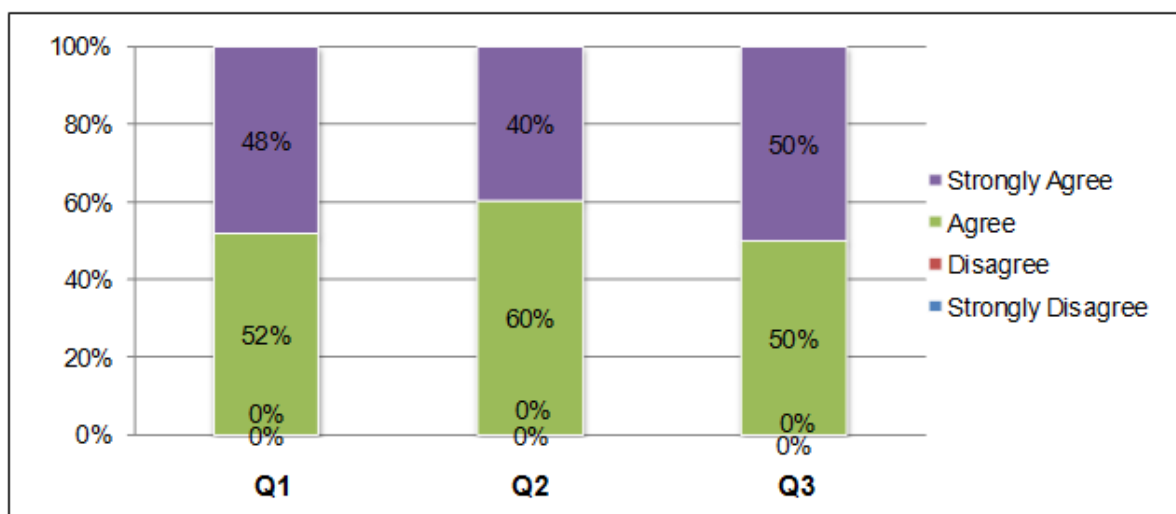


Figure 6. Students' response on integrated learning activity for oral presentation

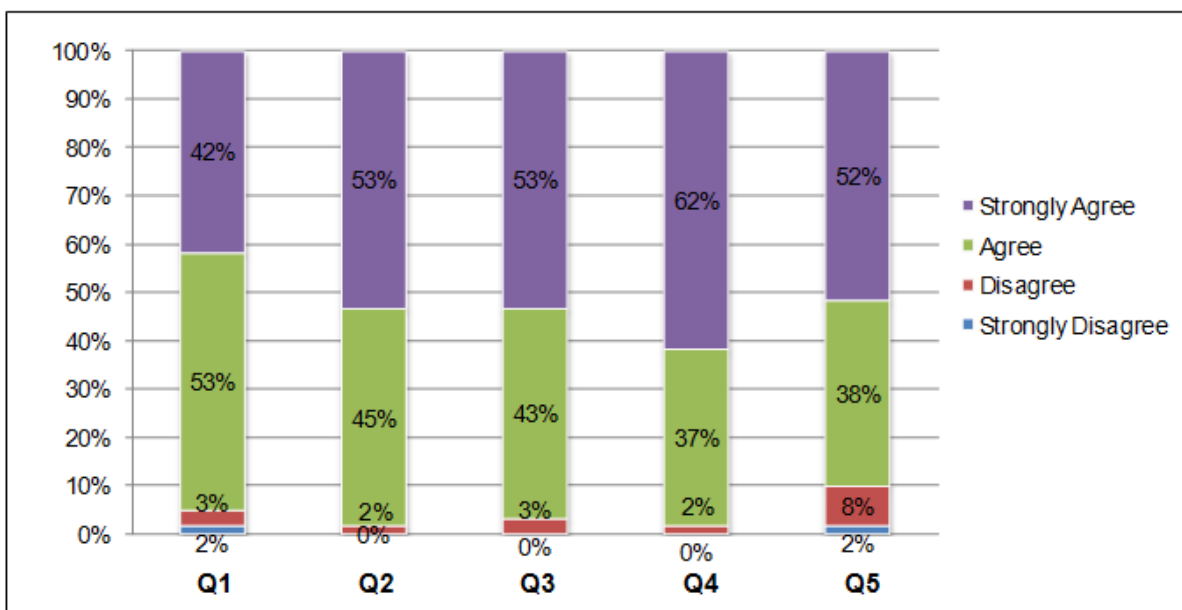


Figure 7. Students' response on joint-assessment by both DCHE and CASS faculty

From these results as well as their journal entries, we ascertained that students liked the “twinning mode” of learning activity. Some responses were as follows:

“It is good to have comments from lecturer on our presentation contents, especially to clear our misconception; as such we could learn from mistakes and rectify them.”

“I could feel the team’s synergy in this learning activity. Everyone is taking initiative during discussion, and we use interesting analogy to deliver the technical contents. It is good to integrate what we have learnt in two modules.”

“The presentation gave me clear picture of having good strategies in preparation of PowerPoint slides and in communication skills such as using the right and appropriate terms of language, put relevant pictures in PPT slides.”

Overall, students also commented that it was a great learning experience as lecturers gave them feedback and suggestions on how to improve their oral presentation skills; along with technical knowledge and concepts at the same time. The oral presentation in such work scenarios gave them a more authentic understanding of a real work context and the importance of good presentation skills along with the appropriate technical content.

ISSUES AND CHALLENGES

The faculty encountered several issues and challenges in conducting such twinning mode of teaching. These centred around the coordination of teaching and assessment in the two modules. Both faculty need to work closely as the “twinning” learning activities and joint-assessment requires a lot of coordination, particularly in lesson planning and administration.

Scheduling of joint-assessment also posed a challenge as both faculty have their individual teaching timetable done separately at the respective school level; and both need to find common time slots that also match with students’ timetables. This usually ended up outside of the formal teaching hours. From the faculty’s perspective, these are additional time commitments over and above their own scheduled teaching hours; which is not captured in the computation of teaching load. As for students, they sometimes have to meet up with faculty late in the evening, even though their classes may have ended earlier, as that is the only time both faculty are available. However, we were relieved to learn from students that the workload is manageable and that many understand the rationale for rigor and demand of the chemical engineering diploma.

A similar challenge emerged concerning faculty giving feedback to students on their scientific written report in a timely manner. The current practice requires student to submit one report to DCHE faculty and another duplicate copy to CASS faculty. After marking the report, both faculty give feedback on technical contents and CDIO skills respectively. However, again due to coordination difficulties, we are not able to provide a joint feedback. Often, each faculty will make separate arrangement that is convenient, e.g. after lecture or during tutorial. In fact, the DCHE faculty is only able to give feedback during the wrap-up session held at the end of the semester.

KEY LEARNING POINTS AND RECOMMENDATIONS

The key learning point from this “Twinning” initiative is that a lot of effort was required from both faculty to successfully integrate the learning activities and assessment in both modules; more so on the following-up debrief, assessment and feedback. The motivation from both

DCHE and CASS faculty in piloting with this initiative is the unwavering belief that we can make a difference in students' learning. The good rapport between both faculty can be considered the deciding factor in such partnership. We are greatly encouraged with the student feedback that such integration had proven beneficial to them, and we see evidence improvement in their written reports. Both faculty will continue to fine-tune this integration effort, in subsequent semesters.

The author felt that a key factor that can help to sustain the integration effort is to have a common timeslot for both faculty to conduct a joint debrief and feedback session. The author, together with her CASS counterpart, will explore such possibility with their respective management, whose support is crucial. However, we recognized that this may or may not be possible due to various timetabling constraints for which the faculty may not be aware. Both faculty will continue with the current form of collaboration and enhanced it via regular communications. The DCHE faculty will also leverage on our current module review system, which include the DCHE faculty as the module coordinator and a few other DCHE colleagues that serve as module team members. We will now include the CASS faculty in the module review team, so that the team can more effectively fine-tune the integration effort. In this manner, other module team members will also learn about the way we organized and integrated the various learning activities and assessment.

Another key learning point for the DCHE faculty is the realization that teaching of teamwork and communication skills are not that difficult as previously perceived. While the full range of teamwork and communication skills are covered by the CASS faculty, the author now feels comfortable teaching aspects of these skills in the engineering context.

Hence, we believe that once engineering faculty fully understand what is involved and the importance of these skills for student learning, they will be less resistant to the idea that they might need to teach such skills within the engineering context. Most significantly, as all faculty are experienced engineering professionals turned academic, they will quickly appreciate that much of the underpinning knowledge for teamwork and communication is, in fact, quite familiar to them. Such knowledge is what Polanyi [12] referred to as tacit knowledge, as opposed to explicit knowledge. This is further elaborated by Sale [13]:

Through the provision of key underpinning knowledge for CDIO Skills, it is possible to bring such tacit knowledge to a more explicit and practical focus. Faculty can then see that they actually possess such knowledge and competence. It is then much easier for them to make direct connections to where and when in the curriculum such skills can be naturally and effectively integrated.
(p.16)

As for future development in this area, we have the following recommendations:

Teamwork and communication skills should be sustained and further enhanced in Year-2 and Year-3 chemical engineering curriculum so students could develop, demonstrate and eventually master the skills to become effective at work as well as in life. The faculty will share the guidelines on scientific report writing that was developed under this initiative with all DCHE faculty so that we can have a consistent approach in assessing students' reports throughout their 3-year study.

We can also leverage on conflicts – potential or real – at the moment they arise, as teachable moments instead of relying on students report in the “Team Effectiveness and Peer Assessment” survey. Faculty could make use of “live” opportunity that presents itself to teach students' in applying conflict strategies to resolve conflicts. Reflection journal on conflict resolution is then a supplementary good tool for students to re-examine their values and identify the causes of conflict, or to suggest actions to avoid the conflict in the first place.

They could learn how to accept different personalities and team role capabilities of their team members, and hence learn to work more effectively with different people.

Explicit teaching of thinking skills can be included in the module *Introduction to Chemical Thermodynamics*, to bridge the gap identified in student surveys earlier. To this end, we can adopt a suitable model of thinking (see [9]), and fine-tune introducing it into the laboratory activities. We can also continue our “Twinning Initiative” with CASS faculty in considering using writing as a form of assessment for critical thinking (see for example, Gunnick et al [13]). Lastly, the curriculum integration could be further extended to mathematics module so students could apply their mathematical skills to solve problem in chemical engineering context. At the time of this paper, the main author is currently participating in an action research project with faculty from the School of Mathematics and Science to integrate mathematics in DCHE curriculum using problem-based learning.

It is also recommended to have a common session for DCHE and CASS faculty to give feedback to students on their written skill and technical contents during the mid-semester. This would result in students having more time to rectify their common mistakes and improve their report writing skill after the feedback session. To facilitate this, a common block-off for both faculties timetable would be desirable. Faculty could work more effectively and provide feedback in time for students to improve their skills. However, we do recognize the practical challenges this may demand in practice.

CONCLUSIONS

The “Twinning” initiative formulated as part of the DCHE curriculum revamp using the CDIO framework has indeed benefited students in their learning experience. Despite the challenges mentioned above; both faculty felt that the results were well worth the efforts; as they had made chemical engineering education more interesting. The feedback from students and faculty were used to drive improvements in the engineering curriculum, especially in the design of learning activities and assessment. The specific areas for improvement have been presented to the DCHE CMT who is supportive of our continuous improvement efforts.

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Biographical Information

Jessy Yau is a chemical engineer turned academic. She is the lecturer in Singapore Polytechnic and has lectured on various topics including chemical engineering principles, membrane separation processes and chemical hazards. Her current portfolio includes course management, implementation of CDIO skills in chemical engineering curriculum and action research on curriculum integration. She has several years of experience in process industry and had conducted live plant training for operators, engineers and students from chemical process and related industry.

Sin-Moh Cheah is a chemical engineer turned academic. He is the Deputy Director in Singapore Polytechnic, overseeing various applied sciences diploma, including the Diploma in Chemical Engineering. He has lectured on various topics including chemical engineering principles, separation processes, heat transfer and equipment, and chemical reaction engineering. His current portfolios include curriculum revamp, academic coaching and mentoring, and using ICT in education. His current scholarly interests are learning pedagogy, curriculum re-design and program evaluation. He held various positions in Mobil Oil Singapore Pte Ltd (now part of ExxonMobil) prior to joining Singapore Polytechnic.

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Appendix 1 Sample worksheet for "Pre-Experiment Exercise"

Diploma in Chemical Engineering
Semester 1, Academic Year 2010 / 2011
PRE-EXPERIMENT EXERCISE

Module Code : _____
 Module Name : _____
 Members : _____

Work in the pre-assigned group as briefed by the lecturer, and discuss as a group and provide the group's consensus to the following questions:

1. List some strengths and weaknesses of each team member:

S/N	Name	Strengths	Weaknesses
1			
2			
3			
4			
5			

2. List down the top 3 goals for your team

(1). _____
 (2). _____
 (3). _____

3. Identify 3 situations whereby failure or non-performance of a member can adversely affect the team performance.

(1). _____
 (2). _____
 (3). _____

4. Set some ground rules for the team to serve as guidelines on how the team will conduct itself over the duration of the laboratory sessions (.e.g. arrangement for meeting, free-riding or non-contributing, disagreement over division of task, etc)

(1). _____
 (2). _____
 (3). _____
 (4). _____

5. Decide how the team will handle any conflict that may arise.

6. Provide information of members' contact details as follows:

S/N	Name	Handphone No.	Constraints – If Any
1			
2			
3			
4			
5			

Return the Completed Form to the Lecturer who will keep it for future reference

CHRISTMAS LIGHTS STUDENT PROJECT

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ABSTRACT

The Christmas Lights Student Project was carried out during the fall 2010. It was done by the first year electrical engineering students. The target of the project was to learn about the electrical circuit design. In Finland, Christmas time is the darkest time of the year. The sun is barely seen in the northern parts of the country. During this time of the year, people like to decorate their homes with Christmas lights. These bright coloured, beautiful decorations bring some light to the darkness and promote the 'Christmas feeling'.

At Kemi-Tornio University of Applied Sciences (KTUAS) the first year electrical engineering students began their path towards Christmas in September 2010 by starting the Christmas Lights Student Project. This CDIO project was designed to offer the students practical learning by doing experiences in the field of electrical circuit design, programmable logic controllers and team (project) work. This paper together with the poster represents the learning objectives of the project, the project work itself and the results which were also introduced at the school event in December 2010.

The Christmas Lights Student Project was managed by three teachers. Ten student teams were working on the project. Each student team had four members and they were allowed to use their imagination and design their very own view on Christmas Lights. For the first year electrical engineering students, it is important that electricity, electrical circuits, electrical components and the difficulties or challenges related to real world design become visible and concrete. The theory lessons on the electrical circuits are more easily forgotten than the practical construction work. It was also seen in this project that the students really enjoyed the design of their Christmas Lights. The project also affected the team spirit positively and the learning outcomes were good.

So, this paper (and poster) represents the Christmas Lights Student Project and gives some ideas on how a successful student project can be carried out. It also introduces the institution of Kemi-Tornio University of Applied Sciences and its participation in the international CDIO conference for the first time. The KTUAS has planned to join the CDIO initiative during the year 2011. Hopefully this paper and the poster presentation together with a strong participation in the conference will offer the school a good CDIO starting point.

KEYWORDS

Project, electrical engineering, product design, teaching.

INTRODUCTION

Kemi-Tornio University of Applied Sciences (KTUAS), department of technology, is a small engineering school situated in Finnish Lapland, by the Swedish border. KTUAS has totally ~2600 students and the staff of ~240. The cities of Kemi and Tornio have a long history and the industry on the area can be considered quite traditional. The main industries include paper & wood processing, steel manufacturing, mining and related engineering work. The engineering department of the school provides education for young and adult students leading to Bachelor's and Master's degrees in mechanical, electrical and industrial management engineering. It can be said that the department of technology of KTUAS is one of the most northern schools in the world giving education at this level in engineering. The distant location and the sparse population in Finland have forced the school to develop the education towards more student friendly direction. Modern technology, possibilities for eLearning, small group sizes and skilled staff together with good contacts with the local Lappish industries can be seen as strengths [1].

Several studies show that, during the recent years, engineering education in Finland has faced challenges. The attractiveness of engineering education is not as high as it used to be – the younger generation may not consider engineering as an interesting field of study. On the other hand, the secondary level education has changed and therefore the capabilities of the applicants have changed. It has also been said that the graduation times of the engineering students tend to be too long and the number of dropouts needs to be decreased [2]. Nevertheless, the main duty of KTUAS as an engineering school has remained the same - it is a continuous challenge to develop the education to meet the requirements of the surrounding industry. Engineers are needed in the region but the skills required are versatile. Today graduates have to, besides good knowledge and skills in technology, be able to co-operate, be international and have good communication and interaction skills. These things (among others) are also pointed out in the CDIO approach [4].

So, what has KTUAS done in order to make the school more appealing and the education more inspiring? One thing is to take a step to the international 'market' - make education more international and participate in the international networks. Participation in the educational conferences, exchange programs and projects funded by the European Union (e.g. Interreg IIIA) has given the school a lot of publicity, new skills and possibilities. The pedagogical and interaction skills of the staff have been further developed by arranging courses and workshops for the teachers and R&D people. Renewing the curriculum has been considered an important task as well. The CDIO framework was found approximately three years ago. It was soon found out that the CDIO way of thinking could offer excellent possibilities to the school. The idea of open architecture of CDIO was very appealing [3], [4]. So, it was decided to collect more information on the CDIO initiative and today the CDIO way of thinking is part of the daily life at the department of technology. In this paper and poster one of the CDIO projects of the first year engineering students is introduced.

The Christmas Lights Student Project was carried out during the fall of 2010. The purpose of the project was to provide a positive kick off to electrical engineering studies and, on the other hand, to offer the students practical learning by doing experiences in the electrical circuit design, programmable logic controllers and team (project) work. This paper (together with the poster) represents the learning objectives of the project, the project work itself and the results which were also introduced at the school event in December 2010.

TOWARDS CDIO AT KTUAS

This chapter provides a short history of some educational activities and methods which have been used at KTUAS during the past few years. The department of technology of KTUAS has quite a long history in project based learning and it has been used in several engineering programmes (information technology, electrical engineering etc.). Other things that are presented in this chapter are the design office model (mechanical engineering programme), summer training and Bachelor's theses, which are without exception carried out in the R&D projects and in the surrounding companies.

Project Based Learning

The project based learning has been part of the engineering education at KTUAS for several years. Single case projects, industrial case projects, laboratory development projects etc. have been carried out in practically every engineering programme. However, the project based education started in the international degree programme of information technology in 1999. In the beginning the programme was called cross-border engineering programme and later on the same concept was adopted to the Finnish IT programme that started in 2001. The number of projects in the whole Bachelor's programme of 240 ECTS accounted for nearly 40% (including Bachelor's thesis, 15 ECTS). Approximately 50% of the time at school was project work. Project/problem based curriculum was established in 1999. There were several CDIO type learning objectives including communication skills, multidisciplinary team work, solving complex engineering problems (tasks with the specified preconditions), taking responsibility and putting theory into practice [4]. During the years, the department of technology of KTUAS has been able to develop project based pedagogy (including the curriculum) and to create teaching and learning methods to meet the expected competence requirements of the graduates.

The project based learning from our point of view means more student centered, interdisciplinary and long term learning activities compared to the traditional lecture based learning. It is also generally expected that with project based learning methods the students learn to transfer knowledge or information from one context to another more efficiently [6]. The main objective of the project based learning is to train students' learning skills, problem solving skills as well as social and group working skills. Learning is typically organized around projects which are built around real industrial case projects. The assessment, guiding and study environment are developed to meet the expected requirements of both the students and the project owners.

Design Office Model

The design office model at Vocational College of Lappia and at KTUAS is part of the mechanical engineering education. This model can be considered an industrial simulation. The design office model combines secondary level education (Vocational College of Lappia) and higher education (KTUAS mechanical engineering for Bachelor's degree). Students of the secondary level study and learn practical skills in a real manufacturing facility. Teachers guide them to learn various practical skills in metal work, manufacturing, machine automation and plant maintenance. The design office model brings together three important industrial branches including manufacturing, engineering design and plant maintenance. The Vocational College of Lappia takes care of the practical subjects and KTUAS mechanical engineering programme is responsible for the engineering design. Mechanical engineering students design the ordered products, create the manufacturing documents and follow the manufacturing process that is carried out by the secondary level students. This model creates a genuine win-win situation where engineering students gain practical experiences

and see how the work really is done in the manufacturing plant. The secondary level students learn how engineering work is carried out in the design offices. The design office model supports learning at both secondary and higher levels. It is also generally expected that this kind of 'do-it-together' model encourages the students from the secondary level to continue their studies at higher levels (e.g. KTUAS) [7]. Figure 1. below shows the main concept of this model [5].

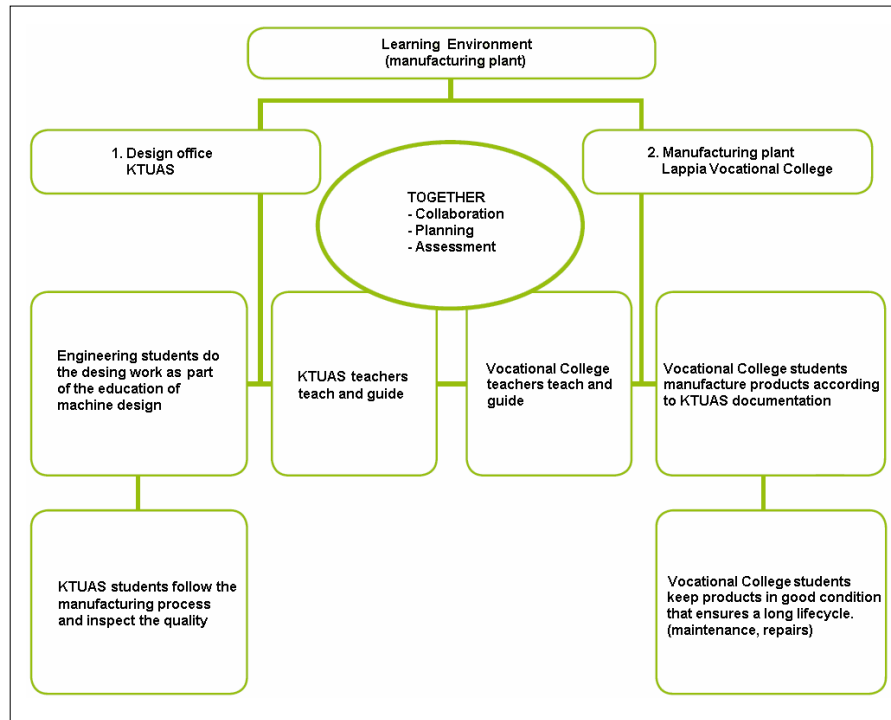


Figure 1. The main concept of the design office model [5]

Summer Training and Bachelor's Theses

The KTUAS engineering students need to have 30 ECTS practical training before their graduation. The amount of practical training may be even 60 ECTS in production oriented programmes. Students normally get training credits during the summer time while they work for the surrounding companies. Summer training is one good way to get real industrial experiences. KTUAS offers training positions at the school too. It is important to ensure that every student has a possibility to get the training credits. A typical training position is in the local process industry (wood, paper, steel). During the first two summers students usually work as process operators. After that they may work as foremen or supervisors. The companies in the area of engineering design offer training positions mainly for students close to graduation. During the summer training the students write a list (memo) of their work and compile a training book (portfolio). This documentation is reviewed and approved by the training secretary who works at the school. Summer training may also lead to a Bachelor's thesis project and even to employment.

Bachelor's theses are usually commissioned by the surrounding industry. The companies co-operate with the school and the students in order to find suitable thesis case projects. Another possibility is to get the thesis project from the school's R&D department. The The bachelor's thesis comprises 15 ECTS and the project usually takes 3 to 5 months to complete. A typical thesis project includes three key parties – the student, the teacher and the supervisor from the company. These three parties communicate and co-operate with

each other, have meetings and try to take the project from start to finish. The communicative culture between the school, the companies and the students has helped KTUAS to develop itself. The local industry becomes more familiar to the teachers and the companies can more easily give feedback to the school. Smaller project cases can become school projects (e.g. cases for project based learning).

Applying CDIO to Engineering Programmes

At KTUAS, the CDIO approach has now been applied to engineering programmes for approximately 2 years. CDIO deals with and helps to recognize similar issues to those KTUAS has faced. The CDIO corresponds to our thoughts of the future of engineering education quite well. Especially learning by doing, problem based approach, project oriented methods and a strong pedagogical grasp are the main reasons why the CDIO framework seems to be a good choice for KTUAS [4]. Currently, the whole department of technology of KTUAS is applying CDIO to the engineering programmes. The CDIO approach can be seen in the curricula as well. There are two main CDIO project courses and several other project type courses that can be seen as part of CDIO way of thinking. The first CDIO project course is for the first year students (=preliminary/orientation project). This project lasts the total of 160 hours (6 ECTS). It has both formal engineering classes and do-it-yourself (with a team) type of construction work mixed together. The CDIO standards are followed and student feedback is collected. The Christmas Light Student Project is one of the preliminary projects. The main idea is to offer the students engineering introduction and teach them to work as groups/teams. Learning new ways to study will ease further studies which are more often completed as a team work.

The second CDIO course is more specialized, wider and longer. It is called an advanced CDIO project. This project is part of the 15 ECTS module and the project itself comprises the total of 9 ECTS (240 hours). The advanced CDIO project takes engineering to a more professional level. There will be partners from industry and thus real case projects. Local industry as well as the community help the school to find case projects. Approximately 30% of the project is dedicated to conceiving, designing and planning type of activities. 30% is operative actions and the rest is mainly reporting and communication. The students work as teams, and several case projects can be started annually. Together with case projects supporting lectures are given and the teachers' roles are mainly to guide instead of teaching.

The CDIO has now been chosen to be the main orientation of the curriculum of the department of technology at KTUAS. The curriculum will be renewed by 2012. The learning environment is also changing towards a more communicative direction. Small laboratories have been built for team work and the number of group work facilities has increased. An important part of the learning environment is the well equipped library in the middle of the renovated school building for the students to study and work on projects.

CHRISTMAS LIGHTS PROJECT

The Christmas Lights Project course started with 40 students in the fall of 2010. Organizing the course was a challenge because of the large number of students. The main targets of the course were stated as follows: Introduction to electrical engineering and engineering studies (especially in the field of circuit design), motivating and getting familiar with the other students and the staff, building up the team spirit and thus make it possible to develop systematic thinking and engineering state of mind in a real case project. It was expected that the targets mentioned would help the students to form their own attitude to the engineering field and help them to work with each other in their future studies as well. The main task of the project was stated freely in order to emphasize creativity and imagination. It was also the time of the year that affected the project topic. So, it was now time to start a project producing colourful electrical Christmas decorations to cheer up the students, the staff and the whole school when the days were getting shorter and shorter.

Planning the Project

The previous orientation projects had given positive learning experiences and built a firm base for further development of project based learning. A lot of positive student feedback and good practices were available. In this particular project, unsatisfactory results were avoided and the course was developed mainly from the students' point of view. The feedback from the previous projects shows that, generally, the students were not happy if the project included too many theory lessons, neither possibilities for learning by doing nor hands-on tasks and not enough time for social interaction, team work, communication or other soft skills. The student feedback also showed that the teacher of the project course should pay more attention to giving individual supportive advice, help if needed, training and more repetition (especially the important topics), allowing students to ask also dummy questions, celebrating success together with the students and just being present with an open mind and having fun with the students. These among other things were taken into account while the course plan for the Christmas Lights Student Project was created.

The Project Start-up

At the beginning of the course the main objectives of the project and other important things were presented to the students. Studying and learning in a project requires some knowledge of the project work itself but also of the common framework, rules, timetables, goals and documentation. The following subjects were covered at the beginning of the course in order to clarify the project:

- team forming, roles of the team members, team tasks and team agreement
- project plan including resource planning, timetable and cost evaluation
- concepts and ideas to be developed further
- communication (memos, weekly meetings, presentations)
- design guidelines, basics of electrical circuit design and calculations
- information sources (Internet, books, datasheets)
- selecting criteria for the components (how to compare products and technical data)
- decision making, design freeze and other ways to proceed
- study environment including laboratories, safety, tools and other workshop hardware
- finishing and verifying the designs (visuality, surface coatings, testing equipment)
- instructions for presenting the products at the end of the project (session, open-door-day, voting for winner, stands, final presentations, local media etc.) and
- final report, feedback discussion, evaluation, grades.

It was decided that there would be ten freely formed teams - each with four members. The only rule in team forming was that in each team there had to be students with vocational college and high school background. The team also had to choose a team leader. At the beginning, introductory lectures and some theory lessons were given to the students, but after some weeks the teams were working freely in the school premises. There were supporting lessons in CAD design, sensors and PLCs and electrical circuit design simultaneously with the project. A course in communication was also taught at the same time. The preparations for the final session (school event) were done by the staff and the students. The idea was to take the final products to the school lobby and the restaurant to delight the people at the school. The products were there for two weeks and the vote for the winner took place after that.

Engineering Communication

There were communication sessions during the project. For example, each group presented the concepts and ideas briefly after the project began. The audience evaluated the presentations and the students gave feedback to each other. In communication, attention was paid to several aspects including:

- reading from the paper
- introducing oneself
- focusing on the topic and use of voice
- eye contact with the audience
- PowerPoint presentation and the slides and
- information contents and clear messages.

The quality of presentations at the early stage was surprisingly good even if the most students did not have former experience in presenting technical presentations. It was also good for the students to share information, know what other teams were working on, see different types of presentations and have possibilities to comment the work of the others. Generally, these communication sessions were ranked as one of the best moments to share knowledge and to learn from each other. After seeing other people's work, new ideas arose and the teams were able to develop their designs further more easily.

Working in the Project

The project work was carried out by the teams. The students were able to decide on the duties by themselves inside the team. Some team members sought information on the Internet while the others wrote reports, programmed PLC or built mechanical structures and frames for their products. Some teams did everything together. The teams shared information efficiently and everyone was aware of the status of the project. Theory and practice were both in use. The teams had to make calculations of electrical currents and power dissipation, for instance. They made the printed circuit boards by themselves and applied many other practical skills. The teams cut, painted, polished, soldered and used several laboratory tools. The safety regulations were followed and the atmosphere in the workshop was positive. After a few months, the work was accomplished and the products were taken to the school lobby and to the restaurant. The exhibition lasted for two weeks and the winner was voted by the staff and the students at the beginning of December 2010.

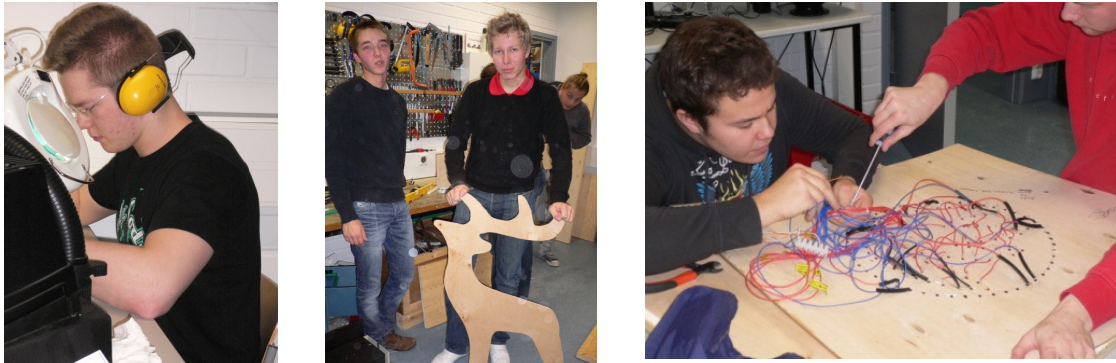


Figure 2. Pictures taken during the project



Figure 3. Circuit board and RGB- led- ribbon installation

The Voting Day

The voting day was a general doors-open-day at the school. The staff and the students from other schools (mainly from the secondary level) visited KTUAS. The visitors could fill in the voting ticket and vote for the best Christmas lights. Each project team had their own stand and the visitors were able to discuss their products and the designs with them. The local media was present as well. The voting day was a big day for the project teams. The teams had to be prepared for any questions of the product. At the same time, they were able to tell the visitors about the engineering studies and their feelings about the school. During the day the students had presentations, they discussed with the visitors and gave interviews to the local media. After the day the voting results were revealed. The three teams whose Christmas lights got the most votes were awarded. The picture of the winners is shown in figure 4.



Figure 4. Top three teams posing

Feedback

At the beginning of January 2011 a feedback session was held. The evaluation and the grades were already given and the students were asked to discuss the project as a whole. Most of the students were satisfied but the evaluation criteria were not clear to everyone. In February 2011 the feedback was collected again. Generally, the feedback was very positive and it showed that the goals of the project were well achieved. The students were still able to remember the project goals clearly and they reported that the CDIO type project is a very good way to study and learn new subjects. Basically, the only negative feedback concerned the evaluation criteria. The students hoped that the criteria should be more clearly stated at the beginning of the project. From the teachers' point of view, the project was quite demanding. However, a successful project like this has a lot of positive impacts and motivated the teachers. The project also created community spirit inside the department. The criteria for evaluation have to be described more accurately in the future projects. Evaluation should concentrate on the process, not on the final product. The criteria should also be simple enough for the the students to understand.

The development plans for the fall of 2011 are ready. Next fall the amount of self evaluation of the teams will be increased. The teachers of the project course will work more closely with the teachers of the supporting courses. The real customers will be linked to the project. Having a real customer will very likely make the project more appealing for the students. The evaluation criteria of the project will also be clarified.

SUMMARY BY THE STUDENTS

Mr. Matti Räisänen and Mr. Jouni Virtanen, Kemi-Tornio University of Applied Sciences

"In the CDIO way to learn, we think that the main point is that the teachers will give us a problem or a task that we should solve by ourselves. We have to find the solutions and figure out what we're going to do and how we're going to do it. This project gave us a great opportunity to start our electrical engineering studies and especially it was good for the students who were coming from high school. However, the students with a vocational school background hoped that the technical side of the project should have been more difficult."

"During this project we had learned a lot of new things about the project work. We have learned of designing, reporting, problem solving, project management and the team work generally. Learning by doing is a great way to learn of different phases of the project work. It will support the other studies too. The Christmas lights student project was a really good way to get known to each other. The team spirit still remains after the project and it is now more easy to ask and get help from the other students when we need it."

"After the project we discussed a lot of what we actually learned and how we feel about this kind of way of studying. The most of our class members are thinking that this was the best way to learn project work and orientate to our electrical engineering studies. In the future we hope that maybe we can do this kind of projects also with the real working life."

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Biographical Information

Lauri Kantola, 33, works as a principal lecturer for Kemi-Tornio University of Applied Sciences. He has completed his university degree (M.Sc. and Lic.Tech.) in mechanical engineering (mechatronics and machine automation). He worked earlier for different product development units and carried out research work at the University of Oulu (Finland). International experience he has gained in various conferences and while working as a visiting scientist at the University of Massachusetts – Lowell (USA). He has also worked in the Shanghai area (China) seeking suppliers for mechanical components and products. His educational career began in 2008. After that he has studied pedagogical subjects in the school of vocational teachers (graduated 2010) and taught engineering students as part of his every day job.

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EMBEDDED DSP INTENSIVE PROJECT 2010

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ABSTRACT

In this paper, we describe the first Embedded DSP Intensive Project (eDSP IP) held on August 2010 in Helsinki Metropolia University of Applied Sciences. The general idea was to bring together teachers from four European University to integrate their high expertise on different electronics and IT engineering fields, thus creating and delivering a series of multidisciplinary lectures. This intensive project was supported by the funds of the Erasmus Intensive Programme of the European Commission.

KEYWORDS

Multicultural Project, Multidisciplinary Project, Intensive Project

CONCEPT DEVELOPMENT AND FUNDING

Embedded technology industry has a demand for skilled engineers, who have strong knowledge of hardware, software, systems, and digital signal processing as well as experience of team-work in multicultural environments. The realisation of this demand was the centre point behind the first eDSP Intensive Programme which focused on integration of multidisciplinary skills in an environment resembling an industrial design environment. Multidisciplinary and an international environment was achieved by bringing together students of various cultural and academic backgrounds (Technology, Electrical and Information Engineering, Mechatronics, and Electronics), while the teaching methods were based on the concept of CDIO.

The concept of the project was initially put forward by the coordinating institution the Metropolia University of Applied Sciences (Coordinating Institution) and later developed with

representatives of Partner institutions through online and onsite meetings, in total three pre-project meetings took place [2]. Partners' network was built upon already existing collaboration; this allowed not only to expand the scope of cooperation but also to combine several activities thus funding pre-project planning. The other partners were Coventry University (United Kingdom) [3], Frankfurt am Main University of Applied Sciences (Germany) [4], and Vilnius Gediminas University of Technology (Lithuania) [5].

Planning of the Intensive Project was done in close collaboration. For instance the first two meetings dedicated to the planning of the project were arranged during a summer school and a teaching exchange visit. Additionally regular network follow up meetings were arranged to ensure all preparations were ready in time.

Once the concept of the project was fully developed an application for project funding was submitted to the European Commission within the frames of the LLP/ERASMUS Intensive Programme by the Coordinating Institution [6]. The eDSP Intensive Programme project was approved. Total duration of the project is three years, however funding is to be allocated on a yearly basis, and requires a submission of intermediary reports and sub application for each consecutive year.

Upon approval of the project the preparation for the first wave of mobility was started. A Project web page managed by the Vilnius Gediminas Technical University was created and used for common document storage area or management board [1]. Promotion of the project to the students (using posters, website and other means) was begun, continuing with the selection of the participants.

During the intensive project lecturers from each partner institution delivered lectures and supervised laboratory work of 50 students from project partner institutions. Students who passed the required parts of the three week long IP were entitled to 10 ECTS points as a part of their professional specialization studies which were recognised at their home institutions.

PROJECT CURRICULUM

In order to study Embedded Digital Signal Processing from an engineering point of view the design, implementation, and operation of a light weight, radio controlled hovercraft was selected as a learning platform. Daily work schedule (please see table 1 for schedule and lecture titles) consisted of lectures and laboratory work in multicultural teams of 3 to 5 students. The total duration of the project was three weeks.

During the first week, the teams had to design and construct the platform using provided materials (two thrust-motors, LiPol-battery, polystyrene sheets, tape, glue, and a sharp knife). At the end of the week, a competition was conducted to determine which design was the fastest. During the second week the teams had to design and implement an electronic control for their platform, which they had to demonstrate at end of the week.

During the last, third week the groups concentrated on the improvement of their platforms for the final, three-stage competition, used as an evaluation method. The first stage was the competition for speed. The second stage involved tests on stability and controllability. The last and most demanding stage involved a line following task, which was a big challenge due to the high instability of the almost zero-friction platform.

Table 1
Class Schedule of the IP

week 32	Mon Aug. 2	Tue Aug 3	Wed Aug 4	Thu Aug 5	Fri Aug 6	Sat Aug 7	Sun Aug 8
9:00-10:30	Welcoming: Introduction to embedded systems: Antti Piironen	Electronic circuits: Andrius Usinskas	AVR lecture: Andrius	PSoc lecture: Antti	Interfaces: ADC, PWM, SPI: Andrius		no work
10:45-12:15	Intro to DSP and digital control: Manfred Jungke	Competition: rules and regulations of the platform: all	AVR lab: Andrius/assistant	PSoc lab: Antti/Juho/Joe	Interface lab: Antti/Juho/Joe/Vilius		
12:15-13:15	lunch	lunch	lunch	lunch	lunch		
13:15-16:30	Group work primer: Antti Piironen	Designing the platform: T.A.'s	Building of platform: Juho	Building: Joe	Testing: Fast track competition (15:00) Juho/Anssi		

week 33	Mon Aug. 9	Tue Aug 10	Wed Aug 11	Thu Aug 12	Fri Aug 13	Sat Aug 14	Sun Aug 15
9:00-10:30	Digital Control: Wolfgang Stief (FH FFM)	Mini workshop: groupwork (Panos + John)	Digital Control: Wolfgang Stief (FH FFM)	Digital Control: Wolfgang Stief (FH FFM)	Signal Conditioning (Antti)		
10:45-12:15	Digital Control: Wolfgang Stief (FH FFM)	Radio interface: SPI+ (Juho)	Digital Control: Wolfgang Stief (FH FFM)	Optical Sensors and Encoders (John Evans)	Implementing: following a line	Heureka, self organized tour @ 11:00am	Cultural activity: Sauna experience (international office)
12:15-13:15	lunch	lunch	lunch	lunch	lunch		
13:15-16:30	Platform design: Power control, steering	Radio interface lab (Juho + Joe + Nicolas)	Groupwork	Labs for line follower + groupwork	Review: Line follower @ 14:00		

week 34	Mon Aug. 16	Tue Aug 17	Wed Aug 18	Thu Aug 19	Fri Aug 20	Sat Aug 21
9:00-10:30	Mini-workshop: collision prevention (Antti)	Digital Control: Wolfgang Stief FHFFM	Group Work	Info for final two days	Presentations: max 15min each	Departure
10:45-12:15	Group work	Digital Control: Wolfgang Stief FHFFM	Group Work	Preparation for final competition	Competition: all previous tasks on one system	
12:15-13:15	Lunch	Lunch	Lunch	Lunch	Lunch	
13:15-16:30	Group Work. Line Follower Competition @ 15:00	Group Work	Group Work	Preparation of presentations	Competition: all previous tasks on one system	
					Farewell party: announcing the winner (all)	

PROJECT IMPLEMENTATION: CHALLENGES AND GOOD PRACTICE

During the project implementation the participants have encountered a number of challenges the majority of which have arisen from the fact that for most students the concept of CDIO and work in international teams was new. Both students and lectures have experienced difficulties due to the fact that students were of different academic background, this on one hand created a real life experience but on the other slowed down progress and sometimes caused frustration within student teams.

In order to resolve these issues academic staff members and lab assistants were always present in the laboratories in order to assist with technical matters as well as provide counselling and act as mentors in case of conflict. The only exception to the rule was the industrial visit for instructors, which was organized on the last Wednesday. Irrespective of encountered difficulties the students have emphasised the development of communication skills as one of the main benefits of the project. They have also positively evaluated the ability to share knowledge and experience different approaches to problem solving.

Another challenge was the evaluation of the work done by the students. The use of competitions as a way to assess achievement has proven valuable; however the predefined

rules had to be adjusted since achievements of the students would vary from week to week. This meant that considerable flexibility and monitoring of the students' progress was needed at all times to make sure that the set rules are corresponding to the work done and fair.

RESULTS AND CONCLUSIONS

Project results were assessed in two stages: 1. Student feedback questionnaire initiated by Fachhochschule Frankfurt am Main University of Applied Sciences [5] conducted in the middle of the IP and immediately after the IP [1]. 2. The Internal Evaluation report carried out by the Vilnius Gediminas Technical University in the form of Interviews with students, lectures and the coordinators during the last two days of the project.

Both evaluation techniques have shown that the students assessed the IP very well (about 4 on scale 1-5), although some concerns regarding "the amount of work" and "The scheduling" were mentioned as well as some challenges mentioned above. The majority of students "Would recommend this intensive program" to fellow students (4.4 on scale 1-5) which indicates that the eDSP IP was very successful and corresponded to the needs of the students. The participants were particularly glad that the project helped enhance their communication, problem solving, team work and other soft skills which lie in the core of Industrial design project and modern engineering processes.

The lecturers participating in the project have positively evaluated the possibility to interact and share experience with colleagues from other Institutions as well as work with students of various academic and cultural backgrounds.

Links to other projects were established. The visiting teachers had excellent networking opportunities with other European teachers, since the IP was organized during our traditional International Summer School, where the teachers are coming mostly from other European countries. We organized teacher's industrial visit to a sensor manufacturing company.

The first eDSP IP was a great success. The feedback from both students and instructors was very encouraging, and we also received a plenty of very good ideas how to improve the IP. During the writing of this paper the planning was going on for the second IP to be held in Coventry on August 2011 and the authors were waiting to get funding decision for the third IP to be held in Vilnius on August 2012.

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CULTURE IN ENGINEERING EDUCATION CDIO FRAMING INTERCULTURAL COMPETENCES

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ABSTRACT

As engineers today often work in intercultural projects and contexts, intercultural competences must be part of the learning objectives in engineering educations. Cultural aspects of engineering education should not just be treated as a question of appropriate communication and teaching: cultural aspects are basically part of engineering disciplines, work challenges as well as the contextual elements in engineering curriculum [1,2].

This is reflected in the aims of the CDIO programme [3,4]; however, the programme, as well as the teaching practises, undoubtedly needs to further develop approaches to cultural aspects in engineering education. Hence the key-question of this paper is how CDIO support the development of intercultural competences in engineering education.

The paper explores the implementation of CDIO in an intercultural arctic engineering programme in Greenland that since 2001 has been enrolling students with special focus on developing intercultural competences. The discussion draws on the socio-technical approaches to technology and professional engineering practises [5,6]. We conclude that intercultural teaching is not just a matter of teaching *in spite of* cultural differences; it involves the ability to communicate *across* differences and foster mutual learning processes and approaches to problem solving. We also point to methods and lessons learned to address this challenge in practice.

The discussions and findings of the paper have relevance in several ways. Firstly, it addresses the continuously development of CDIO, including the current discussion of a new principles [7]. Secondly it has practical relevance to the engineering education, which to a growing degree has to cope with the potentials and challenges of internationalisation of educations and thus intercultural classrooms. Thirdly it has a more general relevance for educational development as engineers most often are working in projects within different cultural settings and contexts and in culturally diverse groups.

KEYWORDS

Intercultural competences, engineering context, authenticity, community networking, programme development.

INTRODUCTION – DEMANDS FOR INTERCULTURAL COMPETENCES

Intercultural challenges in teaching have at most universities become increasingly visible over the last decades as growing numbers of students study internationally and more students have intercultural backgrounds due to immigration. However the basic point of this paper is that these challenges to engineering teaching goes beyond the classroom and must be seen from a broader perspective, as challenges in intercultural communication and cooperation are integrated into the professional profile and activities of engineers.

Cultural aspects of engineering

The intercultural challenges have been an issue in engineering for many years – or at least one which concerned the large number of engineers working internationally. They have acquired new importance as a consequence of the globalisation of education, industry, trade, and knowledge. They have also been evident in relation to problems of sourcing and implementing knowledge, innovation, and technology across culturally different settings. And in terms of culture embedded in technology, there is a growing understanding of the ethnocentric character of technology based on the recognition of its hybrid integration of social and technical elements.

While engineering has always involved the ability to adapt technologies to a given economic and institutional setting, this process of adaptation has usually remained implicit and 'taken for granted'. Technology in general has been seen as socially neutral and therefore also independent of place. Consequently the implementation and adaptation has not been taken seriously either in the training of engineers or in the transfer of technology. However, engineering has never been a 'culturally neutral' endeavour, although technocratic visions and economic interests may have supported such an image. The contemporary professional practices of engineers are, largely, embedded in institutional configurations, national strategies, and cultural norms that define what is considered an acceptable solution and how different problems should be prioritised and solved [2,5]. Consequently culture is not an outside and contextual aspect of technology and engineering, but an intrinsic aspect of how these social interventions in societal development are produced and how they are part of ordering activities, infrastructures and divisions of labour in society.

Therefore intercultural challenges faced by engineering are not just a result of changes in the student population, and the cultural aspects of engineering disciplines and work challenges cannot just be treated as questions of identifying appropriate ways for communication and teaching. Indeed the teaching and the classroom become important settings for exploring aspects of culture in engineering work and for developing and intercultural competences [1]. Teaching has to pave the way for a more reflexive understanding of the 'others' and the professional 'selves' of engineers so that cultural difference is not merely turned into the only significant issue, and even more important that a professional vision is included in the analysis. Further the teaching must provide possibilities for developing the perspective of technology appropriation so that it can be complemented by a broader recognition of the contextual conditions for engineering practices and the attempt to develop and implement technologies in culturally different settings.

Approaches to intercultural aspects in the CDIO programme

So how does CDIO programme related to these different but interrelated perspectives on intercultural challenges in engineering teaching?

Intercultural competences are not directly addresses in the syllabus [3], but an ongoing discussing under the headline of internationalisation and mobility take up how to review and develop the CDIO programme in this way [8]. An international team have presented a discussion paper that provides background research, and this argues for the:

...growing need for international transparency in engineering qualifications, simple cross-credit processes, international dual awards and mechanisms to encourage student mobility. [8]

The discussion paper states that the CDIO Initiative:

... has a number of syllabus topics around internationalization: 3.3 Communications in Foreign Languages; 2.5.2 Professional Behavior; 2.5.4 Staying Current on World of Engineer; 4.1.6 Developing a Global Perspective. [8]

But it also states that neither these nor the 12 standards provide guidelines around internationalisation and mobility. The group therefore propose that the CDIO programme responds more explicitly in the syllabus by formulating an additional standard. This should underline that engineering education:

... prepares engineers for a global environment and to expose them to a rich set of international experiences and contexts during their studies. [8,p.7]

When addressing the cultural competences needed, Campbell et al focus rather explicitly on competences such as teamwork and communication skills. These are to some extend address in the Syllabus (3.1 about teamwork & 3.2 about communication). But as introduced above intercultural competences also need to be addressed as a basic condition and feature of engineering work. Here the existing CDIO programme actually provides important frames in the standards as well as in the syllabus for addressing the 'context in engineering' in the teaching.

A basic CDIO principle demands that the students require:

... an understanding of which includes such issues as the relationship between society and engineering, and ... a knowledge of the broader historical, cultural, and global context. [9]

Crawley et al. further develop on the context in engineering practise and teaching and they claim that

Engineering educators should be aware of, understand, and reflect on this context of professional engineering practice, and be prepared to make it the context of engineering education. [4,p.5]

By underlining the importance of context in engineering, the CDIO programme is criticising the growing focus on teaching engineering science that had developed in the 20th century reclaiming the 'poly techniques'. They concretely outlines a series of aspects of the professional context such as a focus on the needs of customers, a focus on the solution, not disciplines, working with others and effective communication, and they further states that:

... we should make students aware of the new and evolving elements of context, and incorporate them appropriately "sustainability, globalization, geographic dispersion and the human-centric nature of engineering practice. This is the idea that is captured in CDIO Standard One. [4]

Thus the basic principle of C-D-I-O and the elements of the syllabus are in line with this broader understanding of engineering work as basically contextual e.g. 4. Conceiving, Designing, Implementing and Operating systems in the enterprise and societal context. This has been made concrete in formulations such as: 4.1.4. The Historical and Cultural Context; 4.2.1. Appreciating Different Enterprise Cultures; and 4.4.5. Multidisciplinary Design.

The CDIO programme in this way does recognise the basic contextual aspects of engineering; however, it seems ambiguous that it still overlooks the basic cultural implications of the curriculum and the engineering profession. And even if the principles are stated, it is the challenge of the concrete engineering education programmes and concrete teachers to realise the methods, reflections and eventually learning on cultural aspects in engineering.

A basic point for Campbell et al. is that the CDIO programme may improve in this field by more explicitly creating a platform for students to learn important aspects of intercultural competences [8]. Along this line the case in this paper explores how such an intercultural setting can be used to develop such experiences and competences. Though the case we discuss the implementation of CDIO in relation to potentials and challenges of building authentic projects and close interrelations and hence develop the students' basic understanding of engineering as an inherently contextual discipline and the competences needed.

The structure of the paper is as follows. After this outline of our perspectives to understand cultural perspectives within engineering work, we describe how CDIO is implemented in the Arctic Engineering Programme and take out important lessons. In the third section we discuss the cultural aspects of the CDIO programme and of engineering work, and finally we conclude on the points to bring forward the CDIO programme in relation to cultural aspects of teaching engineering.

ARCTIC ENGINEERING – A DEDICATED INTERCULTURAL PROGRAM

The case relates to the development of a full - however small - programme in Arctic Engineering that frames intercultural classes in an explicit intercultural setting.

Since 2001 it has been possible to enrol in a special arctic Professional Bachelor Engineering education in Greenland. The programme takes place in Greenland and in Denmark enabling the Greenlandic citizens to start study engineering in their own region. The programme is anchored at The Technical University of Denmark and has two interrelated targets: (a) to train Greenlandic young people as engineers to take over jobs that today are carried out mainly by engineers from Denmark, and (b) to develop an arctic branch of engineering targeting the special features and challenges of this region. These challenges comprise of the extreme (and changing) climate, the geology, the vast unique geography with small isolated settlements, the fishing-based business sector, the 'double' cultural context of Greenland being a former Danish colony, and the need to support a social, economic and environmental sustainable development of Greenland. The Arctic Engineering programme not only mixes Greenlandic and Danish students, Danish and Greenlandic teachers but also faces the challenges of Greenland being an explicitly mixed cultural setting with which the engineers have to work.

Consequently the case frames rather explicit intercultural settings and learning environments opening for a critical discussion of different aspects of developing of intercultural competences. The implementation of the CDIO programme seems instrumental for the development of intercultural competences and for the development of a contextual approach to engineering. The teaching is now organised with a strong inductive approach and with focus on the special needs and the paper points to methods and lessons learned during the implementation of CDIO to address the challenge of intercultural learning in practice. At the same time the paper gives attention to the cultural bias of the CDIO programme that frames a series of more or less implicit assumptions that constitutes practical and necessary challenges in a modern and demanding engineering job.

Engineering education as part of a sustainable development of Greenland

The Greenland constitution has been changed by introducing home rule since 1979 and self rule since 2009 yet it is still involved in a National Community with Denmark. The large step towards a modernised society that have taken place since the 60's have been planned and carried out by Danish architects and engineers and based on the dominating functionalistic norms. The home rule has to a large extent focused on retrieving indigenous culture through language, art, and traditional hunting skills and identity. A parallel physical planning and institutional development have been sustained and improved dominated by perspectives on technology and economy from the government bodies in Denmark and the societal and industrial norms developing here. In short we can state that the former home rule emphasised the traditional cultural and language aspects of building and sustaining a local culture but basically overlooked the cultural implications of societal change and institutional planning and the importance of engaging in adapting the physical and technological development to the Greenlandic and to the Arctic context.

Greenland has a population of 56,000 inhabitants of which 10% are 'guest' workers from mainly Denmark dominating the management of most public and private sectors. Educating the next generations of Greenlandic citizens constitutes a major element of developing the home rule and the possibility of becoming an autonomous region within the global society. Thus, the aim of is to train engineers to handle not only technical tasks but also to engage in the development of Greenland's material culture, its social constitution and its economic development.

First step of the development of the arctic programme – a transfer

For various reasons, the Arctic Engineering programme was originally developed as a civil engineering programme anchored at DTU. After having completed the first 3 semesters with special arctic related courses in Greenland at the DTU micro-campus at the Building and Construction School in Sisimiut, the students move to Denmark to take standard engineering courses at DTU for another 2 semesters. Followed by a semester of work experience in a Greenland - or another arctic setting - they spend the last year with elective courses and make a final project focusing on an Arctic engineering topic of their choice.

The classes in the Greenland part of the program were very small until 2006. Approximately 10 students enrolled each year, and 1-2 students left during the first semester. Since 2007 the education seemingly has gained more attention among Greenlandic youth and 16-22 students have signed up each year including 25-33% Danes. The programme not only frames the meeting of Greenlandic and Danish students. The first group includes students with mixed backgrounds as there is a considerable tradition for mixed families in Greenland. The teachers are mainly visitors from DTU supplemented by a few local experts and consequently the teaching is in Danish

(Danish is the second language in the schools of Greenland, English is the third language) and it is organised in intensive teaching blocks lasting 1-9 weeks depending on the topic.

Although the intercultural situation in the classroom may seem obvious, this was not explicated in the first years. Neither was the curriculum regarded as an intercultural encounter. In the first curriculum the local arctic conditions for construction work and housing were only addressed explicitly with reference to the local geology and climate and living conditions. The general teaching in math, physics, and even in building construction science were related to the western engineering tradition at DTU with its traditional disciplines, approaches and ways of teaching.

From the very beginning it appeared that the teaching faced serious problems. This was confirmed by the fact that a much larger percentage of the Greenlandic students failed their exams than their Danish equivalents. From the perspective of the teachers this seemed to relate to some problems with the Greenlandic students: 1-4 of the Greenland students in every year group have very poor Danish skills; Some Greenlandic students are very reluctant to speak up in the classroom, to discuss, and to present their work; Some Greenlandic students display 'inappropriate study behaviour' such as showing up late or not at all, and failing to submit their assignments to the teacher and to their fellow students in group work. The 'inappropriate study behaviour' also caused irritation among the 'good students' and resulted in their reluctance to include 'the bad students' in the group work.

The problems outlined above have been discussed at great length among the teachers during the years. A series of different explanations have been launched based on more or less cultural simplifications such as a cultural lack of ability to abstract reasoning, a consensus based society that hampers the students in engaging in debates, and a colonial history of being governed. One fact is that the Greenlandic school system has severe problems of recruiting competent teachers and that the (relatively few) students that reach high school level face problems with coping at this level. A problem of generating enough trained teachers to the schools have grown since Greenlandic became the main language which excluded many Danish teachers. The teaching in the basic school system are developing, but most likely the students – as their parents – still experience a colonial knowledge dissemination embedded in the school system that feels estranged.

Most teachers in the Arctic Engineering programme focused on how to develop responding initiatives and these initiatives were traditionally undertaken by the teachers individually such as: personal phone calls to the students failing to turn up, focused support to some students, integration of more concrete cases in the teaching, and tests and quizzes to provide milestones. In this way one can say that the problems pushed the teachers to some degree to develop their teaching as the teaching 'normally' applied at DTU certainly was not adequate in Sisimiut. Basically most teachers experienced the problem as a dilemma between lowering the level to meet the relatively large group of 'poor students' and giving extensive teacher support on the one hand and preparing the students to the level and the teaching in large classes at DTU on the other hand.

Second step - implementation of CDIO principles

As the quantitative and qualitative evaluations of the programme as well as the teachers' experiences showed unmistakable patterns, a more basic and coherent strategy has eventually been launched that includes a more explicit strategy as regards the intercultural situation and the development of rather different didactic: Since 2007 a curriculum based on inductive teaching has been developed and teaching has been reorganised around what have been labelled 'composite

courses – large interdisciplinary courses each based on local contemporary engineering problems and tasks [10]. The aim of this is to encourage the students' motivation and ability to learn engineering concepts and methods.

The study plan addresses cultural aspects and development of cultural competences in different ways. Some initiatives take up the different cultural outset of the students and aims to build common platforms and visions of the study. One important point is that evaluations have showed that the Greenlandic students have very vague pictures of engineering work and hence what they actually are studying. E.g. there are not many Greenlandic role models and only very few of the students will personally know an engineer. Therefore the students are given a comprehensive introduction to studying and engineering. The first course integrates training in written communication, group work and project management etc., and the students have been offered personal coaching in order to reflect and develop their study behaviour. The following course explores engineering work e.g. through (telephone) interviews with engineers in Greenland – a growing number graduated from the Arctic Engineering programme. Also the students are trained in oral presentation and their own experiences in the class are discussed and related to the intercultural history - and future - of Greenland.

The intercultural dimensions are further highlighted as potential areas for developing competences that are called for in the engineering businesses. In this regard, the challenges must be unfolded and met by the students and the teachers in the engineering problems they deal with in the different interdisciplinary courses: How should e.g. building management processes be organized in intercultural working setting? How should the consequences of the imminent climate change for buildings and infrastructure be dealt with? How do we organize waste treatment in the stand-alone structure of Greenlandic cities? Which urban development is desirable and realistic in the sparsely populated country? And, finally, what is a sustainable development for Greenland?

The integration of the local context and local authentic engineering challenges in the teaching is regarded an important potential for motivating the students and to encourage student learning. In addition, it supports the development of professional competences including intercultural skills: Therefore teaching includes many study trips to see an ongoing construction, to examine a geotechnical phenomenon in the nature, to take samples, or to meet local professionals (most often Danes!). Furthermore, some courses engage in collaborations with the local government or technical infrastructure management in such a way that the work done by students in environmental planning contributes to the environmental action plans for the municipality.

The implementation of the CDIO approach seems to be instrumental for the cultural mixing in the Arctic programme – as well as other programmes - and for the development of a contextual approach to engineering.

First, most courses are interdisciplinary and start with an authentic local case, where the students can get deeply involved in the working of the local arctic societies – often in cooperation with local municipalities. Second, in accordance with the CDIO syllabus the programme [3] focuses on the personal competences. In addition to the group work which makes the subtle cultural differences clear to the students, special courses deal specifically with communication, building of networks, as well as the future job in a multicultural work situation. Even though the students like this form of education it also implies a higher stress on both groups of students. This provides a potential to acquire highly requested intercultural competences for both parties. However, it also constitutes a pressure on the teachers to develop new teaching methods and competences.

DISCUSSION

To sum up the development of the programme, the difficulties of integrating intercultural aspects in the first years of the programme to some extent can be related to the dominating natural science discourses being the core of typical engineering curriculum in which more specific engineering and non-science aspects are not regarded. Furthermore the unsuitable study behaviour of some Greenland students displayed that the teaching transferred from DTU 'did not fit all' and certainly it did not meet the intercultural challenges in the classroom.

From the technological point of view the inductive teaching of the new programme are much better at supporting the development of a new and 'contextual based curriculum'. This curriculum has the potential to address the challenge of how to put the local context - the values, cultures, conditions and competences – into play with the traditional professional knowledge and methods – and in the next section we discuss the challenges of the concrete programme as well as the CDIO programme and how this may improve.

The new curriculum further improves the didactics for the benefit of both Greenland and Danish students. However still a higher degree of the students from Greenland fail exams and leave the programme that is average experience at DTU. We still have to continue exploring the basic challenge of how to understand and benefit from the actual students and their different cultural and personal storylines and meet their 'learning culture' – while at the same time develop the students within the basic frame of teaching prevailing at DTU. In the next section we discuss the cultural bias of the Arctic Engineering programme and relate this to the CDIO programme.

The cultural bias of engineering teaching

The basic intercultural challenge in engineering work is that of 'transfer' – how to transfer science and technology to real life situations. This emphasis the contextual dimension of engineering work and the importance for engineers to develop competences to analyse and meet the complexity of the different contexts that they work in, to go into constructive dialogues with other professionals as well as with end users and to be creative and develop new strategies and solutions.

The intercultural challenge to engineering work is in this context identified as fundamental to how engineering is taught. This is based on the observation that technology and engineering practices always have been developed in a specific cultural setting. This is often not reflected neither in disciplinary knowledge provided in engineering education, nor in the discussion about technology in society. Technology and the properties associated with it, being it the actors involved, are 'black-boxed' and taken for granted as part of the more general discourse on technological change and progress.

The need to explicate context is becoming more visible and engineers will have to learn to understand and handle the implicit social values and demands to the users and operators of the technology [4]. This leads to a new perspective on engineering emphasising its heterogeneous character in combining knowledge from different spheres – both codified in disciplines and non-codified resulting from experience, and with elements from natural sciences as well as social sciences [6]. A perspective that stays in contrast to popular, but newer the less incomplete views of engineering as either applied natural sciences or advanced technical skilfulness.

Development of a contextual engineering programme

This change is also present in the contemporary development of engineering education such as CDIO from being based on and dominated by scientific disciplines to include project assignments, team work, and new ways of assessing the weight between scientific and professional skills. As described in the introduction CDIO is responding to industry demands and include information gathering, communication, business management, project management, and ethical as well as professional responsibilities into the curriculum. After recognising the need for these competences, the challenge is to integrate the competencies, and depending on the specific engineering domain the integration of these new elements with the technological knowledge and experiences is what makes the engineer professionally competent.

Very often the cultural dimension of university training is highlighted in relation to the disciplinary practices based on safe, general and neutral scientific training. But in the case of engineering and the working with technology the professional practice is embedded in the division of labour in society and the organisation of production and regulatory institutions. The organisational unit, being it companies, government bodies or social movements, all work within established hierarchies of norms and managerial power. These hierarchies also define boundaries at which the differences in values and norms potentially create tension between e.g. scientific approaches to problem solving compared to the conditions for practical problem solving. Also societal discourse – which may indeed reflect deeply rooted cultural norms in the forms of visions of development and progress, ethical values on human behaviour, and religious beliefs – has important impact on the conditions for professional practices.

As in the case of environmental management, which is a topic in one of the courses, where the students are to develop a strategy for environmental management in a housing area or in the local city, the social acceptance and standing of science based knowledge very often is confronted with the economic and managerial demands of a hierarchical and private ownership based decisive power in companies. This problem may be seen as rather generic and independent of the cultural norms inside the engineering community and of the cultural embedding of professional practices, government regulations, and the role and power of leadership in business. It even is part of a globalising discourse on sustainability. Still the specific values and assumptions are crucial for how it is possible to negotiate and implement changes in companies in different countries and with different dominant management strategies. Here the differences may sometimes be ascribed to e.g. cultural differences in valuing nature and social condition for human life, but these can as well be related to differences in management styles as to the ethnic background of the owners. The interpretational flexibility of the professionals engaged in intercultural cooperation is important to avoid falling into simplistic explanations featuring prejudices and limiting the possible actions that might lead to change.

This even shows more visible as engineering problems typically are not well defined – sometimes even wicked – from the outset and relevant solutions are not easily picked from an unquestionable catalogue of science backed solutions [11]. An important part of engineering work is in fact about the identification of the problem as well as mapping the possible, often multiple solutions before getting stuck with existing problem definitions and problem solving strategies [12]. Another important element typical for environmental engineering is the need for creating a sound, but still negotiated ground for action instead of waiting for science, government regulation, or customer demands to set the agenda for change.

E.g. the process of discussing realistic solutions for environmental management while having to accommodate both the users, the indoor climate, the environmental demands and the available

technology and economy will support the competences among the students satisfying the aim of making them become 'heterogeneous engineers' [6]. In principle, the Arctic Engineering programme is also more open to developing contextual technological solutions and approaches than traditional discipline oriented teaching.

The cultural dimension of teaching and learning

Educations represent organised settings where often different expectations to the content of the field, the role and form of teaching, and the appropriate students' behaviour are present among the students and the teachers. Most often these understandings are not very visible [13]. On the contrary at universities seems to be a non-spoken presumption that everybody knows what the field is about, what the aims of the study is, and how the study and learning should be performed. To complete the education means to be able to act in relation to these understandings and basically to assimilate them. Hence it is presumed that the students actually share the understandings, the approaches, and the values of the educations and their perspective on the profession.

At DTU the students are basically expected to be personally ambitious as well as development and product oriented. In the case below this shows to be of vital importance and the intercultural settings in the case of course put the implicit cultural and subjective understandings under pressure.

This case provides an example as the difficulties must also be related to more basic cultural and social aspects of the Greenlandic development. The home rule – as well as the teachers - sees the programme as an important contributor to develop local intellectual elite in Greenland. However this aim might not be mirrored in the students – the potential elite. While motivation is a basic feature of most modern approaches to learning, motivation seems to a more complex issue in the Arctic context. Most Greenlandic students that do well express ambitions for their personal carrier and a few students express ambitions of contributing to the development of Greenland. This attitude fits very well with 'the western individual identity' and the teaching in the programme is made to match the correlated - however implicit - image of such a student [13]. However evaluations of the programme indicate that the students that mismanage are not motivated to study engineering – or study at all. Some explain that they choose the programme because it was located in Sisimiut, others that they just 'ended up being enrolled'. We get the impression that they do not relate very much to the idea of being educated. And the alternative - not being educated - is very visible among their friends and families - and they manage, so....

The lack of individual ambitions- or different ambitions – of some of the students – that seemingly mirrors a larger part of the population - are often related to as a cultural aspect of the indigenous consensus oriented culture and by living from day to day – perhaps enlarged by many years of colonial paternity. The Greenlandic society has changes substantially in the last 5 decades including material culture, values and lifestyles. It seems though that the 'different' ambitions of some young people challenge the dream of developing Greenland as an autonomous region in the global developing. It raises a much broader question of how to motivate Greenlandic youth to study and to engage as citizens in the development of Greenland?

This is along the line of the general development strategies of Greenland that are transferred rather uncritically from the European not leaving much emphasis or potentials to the Greenlandic context. This also goes for the educational strategies. CDIO very clearly has a cultural bias as it represents a western approach to personal development and does not reflect other ways of 'becoming and being an engineer'.

The teaching and the development of new work forms frames new implicit understandings of knowledge, learning processes and scholarship – and of the student. The implicit student is not a conscious perception of the institutions, the teachers or the students on the role of the students, but that which becomes present through structures, codes, norms and cultures [13]. An analysis of the implicit student in the engineering educations includes both the above traditions and perceptions of the engineering profession as well as the educational structure, the flow of educational elements, the teaching and the work forms as well as the relations between the participants.

The traditional teacher centred courses are characterised by a high degree of teacher control in the choice of topics, materials, assignments and progression. The project oriented approach of the CDIO is in itself a new 'technology' that is being transferred from different cultural settings as shown in the case below. The Arctic Engineering programme is characterised by a higher degree of student participation and control in formulating the problems to be solved, in the methodological approaches, and in the organisation of the work – and most often by group work. This calls for a new series of skills such as self management, work together in groups and collect and use knowledge critically. The project and hence more context oriented work also means that the students has to work with knowledge as flexible and to combine scientific knowledge with other and very different forms of knowledge - perhaps carried by other professionals or end users. Still the teachers are controlling the basic defining of the subject and the assessment criterion; in practise though the supervision and the assessment. The implicit student in the project work must then have skills to translate the often more diffuse codes within the supervision to assess and progress the work [13,p.55].

CONCLUSION

The standards and principles of CDIO tend to focus on rather instrumental competences when addressing the intercultural aspects of engineering. These include communication, language and cultural insight as a context that does influence the conditions for implementing technology but not change the fundamentals of engineering seemingly independent of cultural conditions. The role of intercultural insight is to make the basically revolutionizing and development producing technology to work in the specific local context.

This contrasts the national, class related and infrastructure specific parts of technology otherwise identified as core to the foundations of engineering practice e.g. concerning the role of technology in relation to the foundation of state, power and the organization of production. In a country like Greenland where settlements and towns exists in distributed structure of economic and infrastructural islands and where land is not privately owned but organized as a collective good that for periods of time can be lent to specific types of use the societal conditions for building technological infrastructures and use the natural resources demands different technological solutions as well as different institutional structures to handle the vital common facilities and to plan for the impact of climate change and global involvement in new industries like mining and oil exploration.

Also the cultural embedding of teaching and learning principles as well as the creation of individual professional identities in a classic collectivist culture where social dependency is the rule, not the exception raises serious challenges to be overcome in the way educations are organized.

CDIO therefore needs to reflect the cultured character of technology itself and the way engineering is defined as part of a hierarchical and commercial as well as institutional national systems not necessarily to accept these frames and contextual conditions but to be able to reflect them when problems are addressed in different cultural as well as nature influenced settings.

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A spiral and discipline-oriented curriculum in medical imaging

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ABSTRACT

This contribution describes and evaluates an experimental combination of a spiral and discipline-oriented curriculum implemented in the bachelor's and master's program in Medicine and Technology. The implementation in the master's program is in the form of a study line in *Medical Imaging and Radiation Physics* containing three disciplines: Imaging modalities, Radiation therapy and Image processing.

The two imaging courses in the bachelor's program and the first imaging course in the master's program follow a spiral curriculum in which most disciplines are encountered in all courses, but in a gradually more advanced manner. The remaining courses in the master's program follow a discipline-oriented curriculum.

From a practical point of view, the spiral course portfolio works well in an undergraduate environment, where the courses involved are to be taken by all students and in the order planned. However, in the master's program, such a tight schedule is impractical since students are likely to seek specialization. From a pedagogical point of view, the spiral curriculum is advantageous to use in the initial semesters where the teaching can be conducted so that the students can build on their intuitive understanding of the subject.

The program was evaluated in terms of the progression in scientific demands in exam from course to course and in terms of the pattern of course selection by the students. The analysis was based on 96 students. The pattern of course selection was found to follow the intentions of the program, thus demonstrating high fulfillment of the learning outcomes.

KEYWORDS

Biomedical engineering, curriculum design, ultrasound, MRI, CT, X-ray, SPECT, PET, medical image analysis.

INTRODUCTION

Medical imaging and radiation therapy have huge impacts on modern healthcare. The broad range of established and emerging techniques relies on advanced equipment, acquisition and analysis methods with important similarities and differences between modalities. Highly skilled technical personnel are needed in hospital departments dealing with biomedical engineering, radiology and radiation therapy, in departments of research, development, service and sales in biomedical engineering companies and in university departments involved in teaching and research. This all relies on competent teaching in this and supporting areas. A successful conduct in this area is not only important for proper treatment of diseases but also for the industry employing candidates with specialization in medical imaging.

The present paper focuses on the engineering education needed to support this area now and in the future. Specifically, the paper describes and evaluates an experimental combination of a spiral and discipline-oriented curriculum implemented in the bachelor's and master's program in Medicine and Technology. It is implemented as two mandatory courses in the bachelor's program and a *study line* named *Medical Imaging and Radiation Physics* in the master's program. It is a unique approach with focus on motivation and where intuitive understanding is taught prior to mathematical rigor.

The spiral curriculum, originally proposed by Bruner in 1960^[1] is based on the idea that teaching a subject can start with an intuitive account - well within the reach of a student - followed by later treatment of the subject at progressively more and more advanced levels. The spiral curriculum is reportedly used and evaluated in medical education^[4], computer networks^[5], engineering^[2,3] and hereunder electrical and computer engineering^[6] and chemical engineering^[7].

Even though the spiral curriculum has some distinct advantages it is not always optimal to implement a program based on this idea only. In the present education, a combination of a spiral and a discipline oriented curriculum was found to be optimal.

DESCRIPTION OF PROGRAMS

Frame

The program in Medicine and Technology was initiated in 2003 and is offered in collaboration by the Faculty of Health Sciences, University of Copenhagen (KU) and the Technical University of Denmark (DTU) where it is anchored at the Department of Electrical Engineering. It consists of a bachelor's and a master's program. The undergraduate uptake is approximately 60 students per year. While approximately 85% of the courses in the bachelor's program are common to all students, the freedom of choice of courses is much larger in the master's program where three study lines are offered: *Signal and model based diagnostics*, *Medical imaging and radiation physics* and *Biomechanics and biomaterials*. This paper focuses specifically on the study line *Medical imaging and radiation physics*.

Course loads are between 5 and 10 ECTS. A 5 ECTS course features one four-hour module of confrontation per week in 13 weeks plus a subsequent period of exam. The total work load is approximately 140 hours for the student, all activities included.

Disciplines

The study line contains three disciplines:

- 1) **Imaging modalities:** ultrasound imaging (US), imaging with X-ray and computed tomography (CT), magnetic resonance imaging (MRI), Positron Emission Tomography (PET) and Single Photon Emission Tomography (SPECT)

- 2) **Radiation and radiation therapy:** radioactive isotopes, ionizing radiation, radiation protection, external beam radiotherapy and brachytherapy
- 3) **Image processing, analysis and visualization:** tomographic reconstruction and inverse problems, image registration/spatial normalization and computational atlases, image segmentation, and deformable models

Learning objectives

The candidate that successfully completes the study line in *Medical imaging and radiation physics* will be able to:^[13]

- demonstrate a comprehensive understanding of diagnostic imaging from physical principles to diagnostic information for modalities such as ultrasound, magnetic resonance imaging, computed tomography, X-ray, positron emission tomography and nuclear medicine
- design and evaluate data acquisition and processing systems, image analysis and computer graphics in medical imaging systems as well as being able to modify existing systems
- develop and evaluate new diagnostic methods and make new applications of existing techniques
- contribute in the set-up, simulation and evaluation of new physiological models with emphasis on diagnostic imaging and radiation physics
- demonstrate comprehensive knowledge of isotopes applied in the major specialties of diagnostic medicine

Course portfolio

The imaging courses are distributed over the bachelor's and master's programs as illustrated in Figure 1. Two of the courses in the bachelor's program are mandatory and one is optional. The courses in the master's program^[13] are so-called *technological specialization* courses among which the students must have at least 30 ECTS to fulfill the requirements of the study line. Courses with two course numbers are given in collaboration by the two institutions behind the program (KU and DTU).

The two imaging courses in the bachelor's program as well as the first imaging course in the master's program follow the format of a spiral curriculum in which the disciplines (or most of them) are encountered in all courses, but in a gradually more advanced and sophisticated manner as the students go from course to course. The remaining courses in the master's program follow a discipline-oriented curriculum concentrating on one or a few disciplines per course.

An implemented curriculum is subject to a number of important constraints. Some of the most important are:

- Pedagogical considerations other than those inferred from the spiral/discipline approach
- Availability of qualified teachers as well as their interests and abilities
- Existence of relevant courses at the time of curriculum design
- Use of existing and new courses in other educational programs
- Desired number of students for a given discipline
- Practical considerations (e.g., experimental facilities, teacher availability)

Due to this, not all disciplines are taught in all spiral courses and not all discipline oriented courses contain a single topic. An overview of topics can be found in Table 1. As seen in this table, even at very advanced levels, some degree of the spiral approach is used (KU181 and KU180).

THE CHALLENGE OF MRI

As an example, consider MRI which is taught in four courses. It is a flexible and demanding method that is now widely used clinically and in research. MRI is a high-profile technique due to the use of exceptional hardware providing extreme magnetic fields. Furthermore, it's highly publicized role in neuroscience makes it a good candidate for motivating students while pushing the limits of their mathematical abilities. Nevertheless, teaching of the subject is often postponed to late stages of educational programs, since advanced mathematics and high levels of abstraction are required for traditional teaching, which often involves elements of quantum mechanics and vector dynamics. The fact that data are collected in reciprocal space adds to the difficulties.

However, the understanding of the basic resonance phenomenon only requires familiarity with magnetism and compasses. This is exploited^[9] in the described study program. Applications of MRI are introduced and a "dry lab" exercise targeting the basic MR phenomenon is conducted already after a few weeks of study in the course 31500&KU008 (shown in Figure 1) introducing several imaging modalities at a basic level^[8]. The students subsequently prepare and present posters on different imaging modalities including MRI.

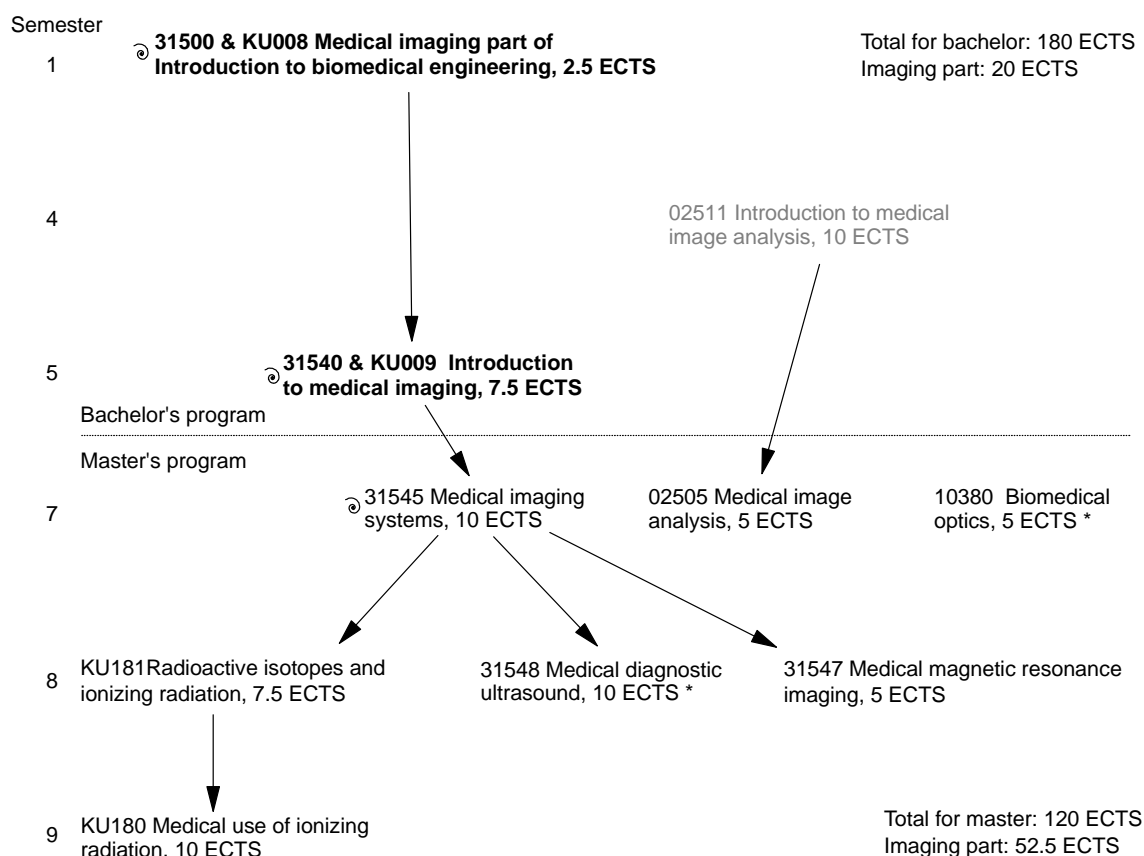


Figure 1. The entire course portfolio in the imaging part of the education in Medicine and Technology. A graphic spiral marks the three courses constituting a spiral course portfolio (remaining courses are discipline oriented). Bold font indicates mandatory courses in the bachelor's program while gray font signifies elective courses. Normal font is used for technological specialization courses in the master's program. Arrows indicate preferred or needed prerequisites. "*" indicates planned courses.

At the 5th semester, in course 31540&KU009, the students again encounter MRI and other imaging modalities. Building upon the compass needle analogy, the students are now introduced to nuclear dynamics, MRI hardware, collective nuclear phenomena, relaxation and contrast manipulation. They write a report following an exercise where an unknown object is scanned using several modalities^[10]. The interactions between MRI hardware and nuclear samples are explored in an MRI simulator^[12] allowing for dry lab experimentation with MRI hardware that is not otherwise possible at this level due to safety and resource constraints.

In the first semester of the master's program (7th semester in Figure 1), the course 31545 increases the mathematical emphasis. MR imaging methodology and reconstruction techniques are introduced and techniques are demonstrated in vivo during a site visit. Spin dynamics, contrast manipulation and imaging concepts are explored using simulation software developed for the purpose^[11]. External lecturers present clinical and research applications and reconstruction of MRI images is done in a lab exercise. This course is the final one in the spiral curriculum and is followed by a specialized MRI course, 31547, focusing on advanced concepts and applications (quantitative imaging, spectroscopy and functional MRI) for students who wish to specialize in the subject. The students contribute to the lectures and conduct measurements in small groups at collaborating hospitals.

Table 1 Approximate content in percent of the different courses. Course sizes and location in the program can be seen in Figure 1. The course Radioactive isotopes and ionizing radiation is not tabulated as the content falls outside this table. "*" indicates planned courses.

Course	X-ray CT	SPECT/PET	MRI	US	Optics	Therapy	Analysis
Intro. BME (imaging)	15	15	30	30		10	
Introduction to med. imaging	23	23	23	23			8
Intro. to med. image analysis	5	5			5		85
Medical imaging systems	29	13	25	33			
Medical use of ion. radiation	30	30				30	10
Medical diagnostic ultrasound*				100			
Medical image analysis	5		5		5		85
Med. magnetic res. imaging			100				
Biomedical optics*					100		

EVALUATION

The previously mentioned learning objectives are normally obtained by passing the exam of 30 ECTS of imaging courses in the master's program in Figure 1. If the prerequisites are adhered to, the present degree of implementation allows for a number of combinations considered below. Thus, in the evaluation of the program it is relevant to consider the progression in the level of difficulty in the exam and which pattern of courses that the students select.

Progression in scientific demands in exam

In order to illustrate the progression in exam requirements, examples of the exam in three courses are given below.

The exam in course 31540 Introduction to medical imaging is based on one report and one multiple-choice exam. A typical question regarding MR is:

Which of the following combinations of static and RF magnetic fields is used for MRI?

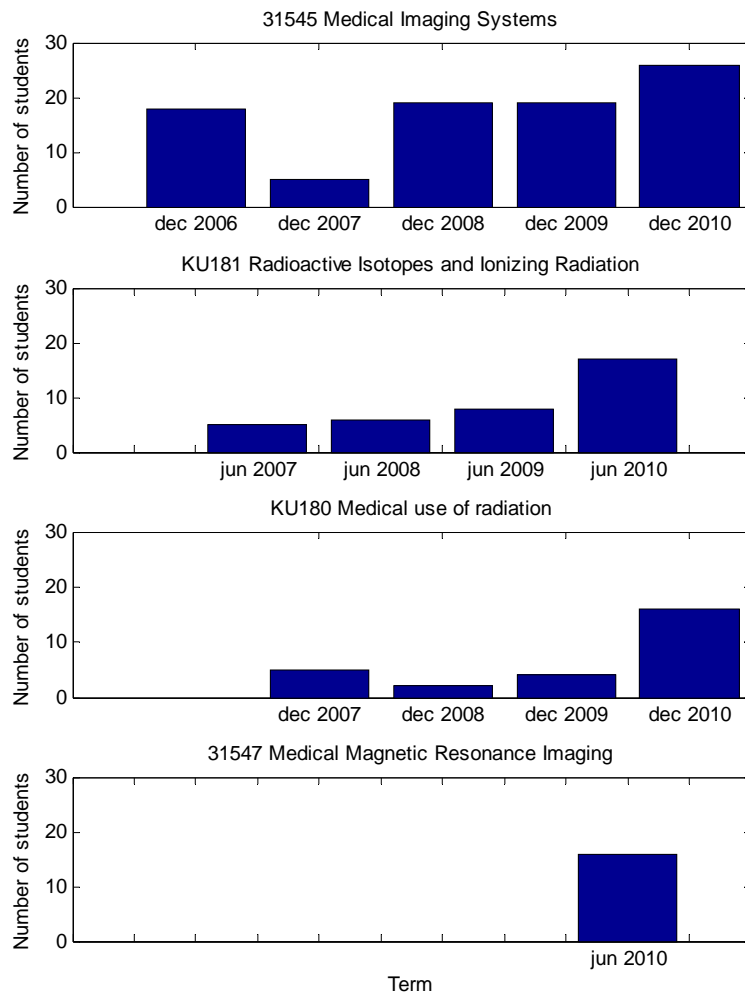


Figure 2. Number of students passing the exam to and including 2010.

- A) A static field and a weaker radio-frequency field oriented perpendicular to the static field
- B) A static field and a weaker radio-frequency field oriented parallel to the static field
- C) A static field and a stronger radio-frequency field oriented parallel to the static field
- D) A static field and a stronger radio-frequency field oriented perpendicular to the static field
- E) Do not know

The exam in course 31545 Medical imaging systems is based on three reports and an oral exam. The central question in the oral exam regarding MR in this course is:

- Explain the physical interaction mechanisms for MR scanning

The exam in course 31547 Medical magnetic resonance imaging is based on three reports and an oral exam. One of the ten topics for the oral exam that best matches the above is:

- Explain inhomogeneity and artifacts

Pattern of course selection

The evaluation presented here is limited to students passing the exam in at least one of the imaging modality courses 31545, KU181, KU180 and 31547. This criterion yielded a total of 96 students. Figure 2 shows the number of students passing the exam up to and including 2010. In order to study how well the learning objectives were met by the students, Table 2 shows how many students took the course chains of Figure 1. The numbers in the table are based on the same data as in Figure 2.

Table 2 Number of students passing the exam in different combinations of courses and their pre-requisites (as shown in Figure 1). "-" indicates not counted or not applicable.

Course	31545	KU181	31545 and KU181
KU181	31	-	-
KU180	0	0	24
31547	15	-	12
KU180 and 31547	-	-	11

The first row in Table 2 concerns course KU181. Thirty one students have taken this together with the prerequisite course 31545. The second row concerns course KU180. None of the students have taken this without the prerequisites. Specifically, 24 students have taken the complete chain of "ionizing" courses: KU180-KU181-31545. Eleven out of these 24 students have taken all four courses as seen in the fourth row.

Going back to the third row, 15 students have taken course 31547 with the required prerequisite course 31545. Of these, 12 have also taken course KU181. And as stated above, the vast majority - 11 students - have also taken course KU180.

Only students from the education Medicine and Technology are included here, so the actual number of students on the courses are typically higher.

DISCUSSION

From a practical point of view, the spiral course portfolio works well in an undergraduate environment, where the courses involved are to be taken by all students and in the order planned. However, in the master's program with a large degree of freedom of choice, a schedule as tight as that is often unpopular and impractical, since students are likely to seek specialization in just one or a few areas. With respect to resources, in a spiral course, more teachers have to agree and coordinate their schedule than in a discipline oriented approach. Thus, the more expensive spiral curriculum should be used only when the pedagogical advantages at least outbalances the extra costs. With respect to teachers in the program, some are staff members while others are affiliated with hospitals or other research institutions. However, only faculty staff are affiliated to such a degree, that they are able to participate in several courses (within MRI, the same person is responsible for all MRI education).

From a pedagogical point of view, the spiral curriculum is advantageous to use in the initial semesters: The earlier a discipline is introduced, the higher a level can be reached in the most advanced course, everything else being equal. Starting a discipline in a course at the first semester requires that the teaching builds on the student's intuitive understanding. This is only possible for maybe just a few weeks. After this, the learning objectives in reach with just intuitive understanding are exhausted and further progress need skills (e.g., mathematical) from courses that the student will not meet until later. It will therefore be optimal to continue with a new discipline, thus initiating the idea of a spiral approach. Doing this yields some other advantages:

- It encourages student involvement and learning, which is particularly important at the entrance of the program
- When teaching several disciplines in the same course, analogies between them are easily drawn, broadening the horizon of the students
- The students are taught about all modalities, which is deemed important since students with no knowledge about other disciplines than their own easily become narrow minded

This intuitive understanding of the students can be exploited in all disciplines, except those requiring extensive knowledge from the very beginning. This paper has exemplified how even MRI can be taught in the first semester, as long as only the most basic aspects are considered and analogies to aspects of every-day-life are used (e.g., compass needles).

The pedagogical advantages of shifting into a discipline-oriented approach during the master's program are partly that students at that stage will most likely want to concentrate on one or a few topics and being able to do that will be more motivating. Also, the simple fact that a new format provides a "change of air", also increases motivation. From a teacher point of view, it is easier to make changes to content in discipline oriented courses.

Nevertheless, to some degree, the spiral curriculum is exploited all the way through the chain ending with KU180, where all ionizing disciplines are included. Coherent tuition coordinated with all teachers and with mutual knowledge of their respective fields is essential for the success of this course model.

A central part of success in a curriculum like this is the availability of knowledgeable and pedagogically experienced teachers that can participate in all - or most - of the courses. It is important that the teachers manage to dispense the material to the different courses in a balanced way and that he/she is capable of teaching the subjects at a beginner's level as well as at an advanced level.

A quantitative evaluation is presented in Figure 2 and Table 2. The results are given in actual number of students, not as relative numbers for two reasons: a) These data do not reflect a "steady-state" condition since the education is quite young (the master's program had its first uptake in the fall of 2006). b) It is very difficult to establish a robust reference. One possibility would be to use the number of students that have taken the first course in the master's program, 31545, but the time period in which this number should be counted is difficult to establish, since student progression speed is heterogeneous and students does not necessarily take courses in the same order (e.g., due to periods of studying abroad, projects of directed research, conflicts between course schedules, personal matters).

Based on the data in the last two rows of Table 2, it is shown that the students follow the suggested chain of courses. Apparently, this seems to have been successfully communicated to the students via information meetings, the homepage^[13] of the programs and the fields of "Qualified Prerequisites" in the course catalogue^[14]. The data also shows, that the longer the chain of courses, the fewer the number of students. Apart from the data being non-steady-state, this is also due to the way the requirement of the master's program is set up: the students must select 30 ECTS (as a minimum) of the entire pool of Technological specialization courses, which also covers the courses in the remaining two study lines, not considered here. Also notice how the yearly number of students completing KU181 from the beginning until present increases nearly exponential (second panel of Figure 2), made possible by the increasing number of students that have passed the exam of 31545 (first panel of Figure 2). This pattern is somewhat repeated for course KU180 with a natural time lag of one semester.

CONCLUSIONS

This paper has described a spiral and discipline-oriented curriculum in medical imaging implemented in the educational program Medicine and Technology, offered in collaboration by the Faculty of Health Sciences, University of Copenhagen and the Technical University of Denmark. The program was evaluated in terms of the progression in scientific demands in exam from course to course and in terms of the pattern of course selection by the students. The analysis was based on 96 students. The pattern of course selection was found to follow the intentions of the program, thus demonstrating high fulfillment of the learning outcomes

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INDUSTRY INITIATED INTERNATIONALIZATION OR JTH GOES TO CHINA, A CASE STUDY

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ABSTRACT

"Students should learn Chinese" was the trigger words from the industry "because 99% of all promotional materials sold in Sweden come from China". This seemed unrealistic at first, but eventually developed the idea that students should visit China to meet the business community in the East and what today is everyday life for many Western companies. This paper describes a project carried out during 2009 when about 30 students at the "Graphic Design and Web Development" programme at the School of Engineering, Jönköping University went to China to study for about five weeks. The goals of the project are to: create conditions to increase the employability of students, increase opportunities for active collaboration between students and industry, stimulate students' creativity and entrepreneurial spirit, and promote understanding and respect for other values, e.g. cultures and traditions. The students were given a long list of different tasks, one of them was to do a specific task for a Swedish company; finding new and interesting products that could be used as giveaways while others were asked to negotiate better prices from alternative providers. They worked in small groups of about three people and all groups had unique projects. The principals of the project were all wholesalers of promotional products. The result was a great success; all groups did present complete and precise calculations for their products and it is notable that the students after the trip have become both more discerning and more likely to continue their careers in an international environment. The percentage of students going abroad to study were much higher among them who participated in the China project than among them who didn't.

KEYWORDS

Internationalization, Industry involvement, China,

BACKGROUND

Even before the School of Engineering at Jönköping University (JTH) joined the CDIO Initiative, Industry Involvement and Internationalization was high priority when planning programmes. JTH has a target that 25% of the students will study abroad during or after their education, which is one of the highest rates in Sweden for programmes without compulsory

studies abroad. In addition to this objective a lot of effort is put into including other students in the outcome of internationalization efforts, including guest speakers, theme days and not least the integration of international students in regular courses. No student graduates from the School of Engineering without having read at least one course given in English.

Another cornerstone of JTH's policy is cooperation with the local industry. Already during the first year of the engineering programmes a course starts that extends over the first two years, where a significant part consists of visits to some of the region's businesses. Students do this in small groups and therefore they get to know their supervisors. Hopefully this gives the students an understanding of what will be required of them when they have completed their studies and begin their careers. It is also quite common for students doing their theses at the companies they have studied and it is not uncommon that students get their first job at these companies. JTH has traditionally focused on programmes at the Bachelor level (3-year programmes), so when the programme in Graphic design and Web development was planned to be only two years it was soon realized that the short time available made it difficult to follow the tried and tested model. Instead of having industrial involvement as a separate course it was chosen to integrate this into the regular courses. Already during the first semester a partnership was developed that includes a trade association for promotional companies (PWA). During their first year, students will work with a couple of PWA's member companies through various projects, such as manning of the exhibition booth at the annual promotional fair at Elmia, proposing booth design for PWA at the same fair, design proposals for promotional products and developing graphical profiles for the member companies.

"Students should learn Chinese" was the trigger words from the industry "because 99% of all promotional materials sold in Sweden come from China". This seemed unrealistic at first, but eventually developed the idea that students should visit China to meet the business community in the East and what today is everyday life for many Western companies.

The project idea was simple: students were divided into groups and each group was assigned to a company within PWA. The task given was to come up with a product proposal for the company. The product should come from China and the students were expected to find the product/producer and do all the calculations for the entire chain from manufacturing in China to "ready to sale"-products in Sweden. How this was done is described below.

PURPOSE AND OBJECTIVES

China of today is one of the countries with the highest economic growth in the world and in China there is a new and exciting market with great potential for many industries. It is a country with a lot of knowledge to learn from, but we also have much to share. The outcomes of the project for students are to increase their own market value and become more attractive in the labour market, both for Swedish companies setting up in China and for Chinese companies who choose to start operations in the Western world.

In order to increase understanding and create conditions to interact with people from other countries and cultures students should get a glimpse of both etiquette in the business world and how it is to live in a country with completely different standards and conditions. As the project runs for quite a long period the students have time to establish contacts with industry, both nationally and internationally, and to make new friends that can come handy in the future. They approach and understand their future role of profession in a better way and get a broader perspective on themselves, their own knowledge and their professional context.

For JTH the purpose was to find new ways for co-production between public and private sectors both nationally and internationally. More and more of the daily work will be of a bi- or multinational nature so it's becoming increasingly important to provide students with an

international outlook. The purpose for JTH is also to broaden the concept of internationalization and spread the internationalization to those who choose not to go abroad for studies at all.

The goals of the project therefore are to:

- create conditions to increase the employability of students
- increase opportunities for active collaboration between students and industry
- stimulate students' creativity and entrepreneurial spirit, and promote understanding and respect for other values, e.g. cultures and traditions.

IMPLEMENTATION

The China project was carried out during the spring of 2009 and consisted of three phases: preparations at home, a five-week stay in China, and reporting and examination after the return to Sweden. The project was a 15 credits course, where students could choose whether they wanted to make a workplace based project in Sweden or participate in China project. About half of the students did choose to go to China. During the preparation phase, a series of lectures were given, designed to provide an understanding of Chinese history and culture. It also included a short series of lectures about the basics of the Chinese language. The aim was to prepare the students that they might experience China as very, very different and also to make them aware of the risk of excessive cultural clashes.

To complement the theoretical parts the students were assigned a real task by their host companies. To solve the task and get a deeper knowledge in the field the students started and ran a fictitious company. Within the company, the students were supposed to:

- find and connect with potential subcontractors
- assess those suppliers in terms of quality, delivery and production
- deliver results to their clients and recommend appropriate subcontractors
- create an administrative system with web interface for time reporting and management of the project
- create a professional magazine with articles and photos, written and taken along the project
- create a video documentary about the trip, which has "young entrepreneurs who want to expand in China" as the target group
- create an archive of photos taken during the trip and do a photo exhibition
- design logo and visual identity for their "business"

The students travelled in small groups according to their own planning to Shanghai, where the whole group gathered at a particular place at a set time. All showed up, nice and clean, and phase two could begin.

The first days were spent in Shanghai, with a number of lectures given by Swedes who have lived some time in Shanghai, employees by Swedish companies and representatives from the Swedish Trade Council in Shanghai. After the days in Shanghai, the students travelled to Ningbo, a small city south of Shanghai. Little should be read in Chinese - Ningbo has about six million inhabitants. In Ningbo the students were accommodated at Zhejiang Wanli University, which has about 20 000 students. During the three weeks lectures, field trips and individual work were mixed with the intense social contact with Chinese student, following living on a Chinese campus.

The highlight of the visit was a two-day visit to Yiwu known as "the exhibition city", where over 30 000 companies exhibit at a permanent exhibition that each year is visited by more than 2 million people. Exhibitors are manufacturing companies and here you can find more or less "everything". There is also help available to find the right freight and customs costs for

the whole world. Here, the students had every opportunity to find products that could fit their clients at home in Sweden.

Home at last, final stage began which meant to bring order to all impressions and sort all the collected materials. All work was reported to the School of Engineering in both oral and written form. To the external clients results were reported in the form of a written report and a presentation at the company. Most groups had handled their planning well delivered everything in good time. Other groups learned about the importance of good planning and had to work around the clock a few days.

RESULTS

The students worked in small groups of about three people and all groups had unique projects. The principals of the project were all wholesalers of promotional products. Some of the groups had the task of finding new and interesting products that could be used as giveaways while others were asked to negotiate better prices from alternative providers. The more precise demands made by their principal, the better were results from the students. One group had as task to find new gift boxes for chocolates. At the fair there were an entire department with that type of articles and the students could move from booth to booth and gather samples to take home to the principal company back in Sweden. Another group got the assignment from their PWA company to negotiate better prices for their product. This was obviously a much harder task. A third group were asked to find a supplier of 10 000 printed balloons to push a company name. All groups were able to present a result to their respective PWA-business, although the quality varied. This was mostly due to the difficulty of some of the tasks.

A major problem that students were aware of but not adequately prepared for was that most of the exhibitors at Yiwu, were strictly Chinese-speaking and just a few spoke some kind of broken English. This language confusion of course made it difficult to negotiate prices. Another problem was that the exhibitors were not particularly interested of quantities as small as 10 000 balloons, they would have preferred it to be at least 100 000. However, that was also an experience.

All groups did present complete and precise calculations for their products including; purchase price, customs and other import charges that might have to be added before the goods is safe in a ware-house in Sweden. It turned out to be quite an interesting and demanding task to cross the language and culture barrier and come to an understanding with skilled Chinese business men and it led to lots of frustration among the students. But for them who made it, it gave both confidence and insight about themselves that they were capable of handling completely new and difficult situations. We have noted that the students after the trip have become both more discerning and more likely to continue their careers in an international environment. The percentage of students going abroad to study were much higher among them who participated in the China project than among them who did choose to stay in Sweden for internship. In their application for studying abroad many of them stated that they had been inspired during the China event. To live five weeks in a country very much different from what they are used to seem to have made them both far-sighted and self-conscious.

DISCUSSION AND CONCLUSION

The project was successful in all aspects. Students experienced the period as highly instructive and interesting, and interviews with some of the groups revealed that the project objectives were met more than enough. The project provided an opportunity for students who were not used to international travel to "try out" study abroad in a more organized form. The project also has increased the students' interest for international studies as well as to work abroad. Whether the students are more attractive on the job market or not is yet too early to measure, but with greater confidence and with a CV that includes a five weeks project in China we feel fairly confident that this is the case.

The most obvious problem the students experienced and not were prepared for was that the representatives of companies in China were not knowledgeable in the English language, impeding negotiations. Another problem was that before the trip, the students had met their clients (companies) at only a few occasions. The result would have been even better if the students had been able to do a shorter period of internship at the company before the trip to learn more about the company's business and culture. It is very important that businesses are aware of the assignments they give to students, and that they take their responsibility to inform clearly what they expect. The students are inexperienced in the area and need much guidance.

For JTH's part, the project has led to a new way to interact with industry and this collaborative form could be used for other programmes and with other industry partners. It can be seen as an asset, both from a marketing standpoint and in terms of internationalization. We can see great development potential with this type of projects. The profile the education and training of the Graphic design and web development programme has can allow the students to cooperate with Chinese companies in a variety of ways. For coming years we see a development towards delivering more and more services to Chinese companies, as China goes from being one of the largest exporters of goods to one of the worlds largest importer of services as well as complex products and systems.

Biographical Information

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ASSESSMENT – DIFFERENT METHODS OF PROGRAM EVALUATION

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ABSTRACT

This paper introduces the thoughts and effects of changing the evaluation procedure for evaluating content and quality of courses and study programs at the engineering college of Aarhus.

There will be a description of the new evaluation method the pro's and the con's in changing from a fixed procedure, to a working tool in education enhancement.

In the spring of 2010 the board of studies at Engineering College of Aarhus proposed a change of the evaluation method for all of the engineering bachelor studies.

Before that time students did evaluate their conception of course quality by using a standard evaluation procedure in evaluating the courses they have attended at the end of each term. The procedure consisted of two steps, first a midterm evaluation held orally, with the purpose of adjusting differences between teacher and student expectations of course activities, secondly a written evaluation with 6 questions addressing the students motivation and skills, the learning goals of the course, the workspace, the course curriculum and work load, the learning activities, and the relevance of the course

In short this evaluation method focused on static half year observation on the student comprehension of the course, the teacher and the facilities. In many occasions the feedback was best viewed as documentation of facts.

The main purpose for developing the new evaluation procedure was to evaluate course issues that could give valuable contribution to the teachers on-going refinement of the learning activities in a course, or to the overall structure of the terms and the education as a whole.

KEYWORDS

Evaluation methods, course and program development

INTRODUCTION

To evaluate is to uncover the value of a given action. The methods chosen for evaluating a specific educational activity is therefore fundamental in investigating and substantiating a particular link between effort and outcome.

One should always question what purpose a given evaluation procedure should fulfil, in order to aim the focus on evaluating the right issues.

THE ORGANISATION OF STUDIES

The study programmes at the Engineering College of Aarhus is organized as shown in figure 1.

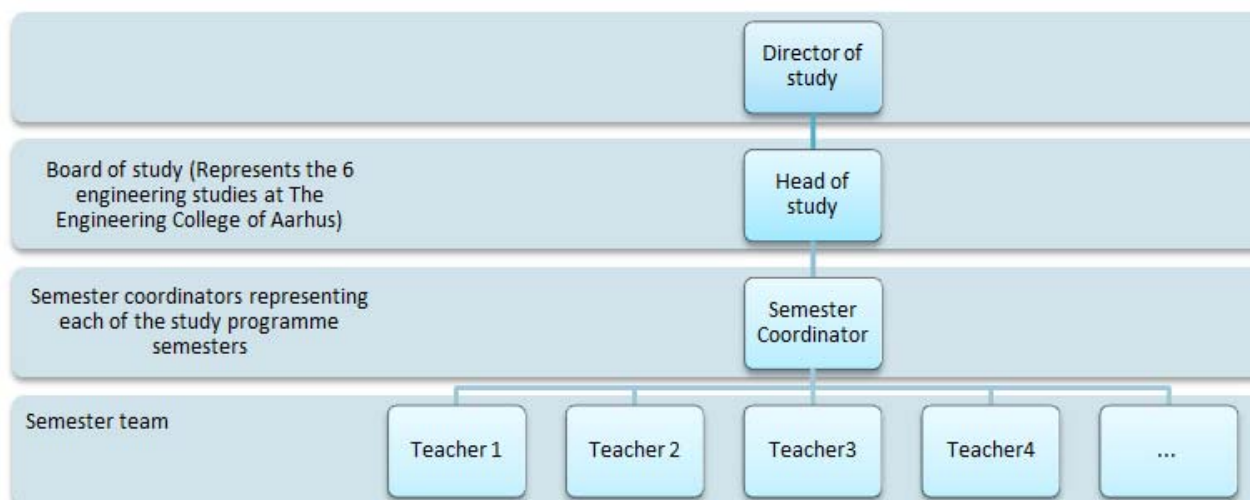


Figure 1: Organization of studies

EVALUATION

To ensure the motivation of both students and teachers in contributing to the evaluation procedure, it is important that only issues that we actually can take action on are included in the evaluation.

For the students and the teachers there is an advantages in obtaining knowledge about the satisfaction or lack of the same from a learning activity, about students' perceptions of whether teaching have been at an appropriate level and whether they have been able to work with their knowledge in an appropriate manner.

The disadvantage not often mentioned is that is it not without personal costs to teachers to be evaluated. While a positive evaluation can confirm the teacher in that he has chosen the right line of work, a negative evaluation can cause the teacher to begin doubt his skills as a teacher. It is therefore important to give thought to the entire evaluation procedure, not just to perform the evaluation but also to work in a constructive manner with the results.(1,2)

The following 4 elements are to be considered:

- What to uncover: The purpose of the evaluation must be clear
- How to uncover: The focus must be on issues that can and will be responded on
- How to engage: The method must ensure involvement and dedication among the students, the teachers and the head of study
- How to take action: Clarity in the methods used for enforcing the evaluation results

What to uncover:

The change in evaluation method rose from a wish to supplement the student satisfaction focus in the evaluations, with a part that could ensure course and teaching development. The study program should be evaluated in a way so that active students, in addition to giving feedback, also is involved in improving the teaching-, learning- and study environment. The evaluation is to be used as a tool for ensuring the development of training in each course, the coherence and development of teaching across courses, and ensure a study related progression between semesters, as illustrated in figure 2.

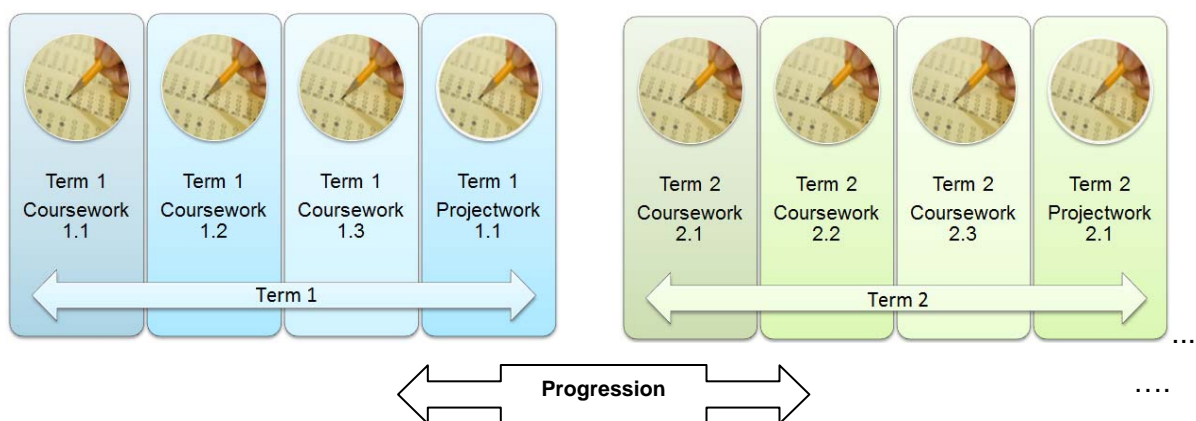


Figure 2: Study program evaluation

How to uncover:

It is important that the educator have a variety of evaluation tools to choose between, when the purpose is to uncover a specific aspect of a learning activity, (that is project work, teaching, laboratory work). The evaluation method should fit the needs to uncover attitudes, knowledge or the conduction of the student integration in the coursework.

Coursework

The courses in the study program are at different development stages and should therefore be evaluated accordingly.

A newly developed course has other evaluation issues, than a well-integrated older course. This is also the case for a course with a teacher new to teaching, or used to teaching but new to the technical field of the course.

The following issues should be evaluated in every term

- Coursework, including course contents, teaching methods and interaction between teacher and student.
- Students' prerequisite before the course.
- Students' preparation and independent work.
- Students' learning environment and the fellow student engagement.
- The learning targets utility and clarity.

These are all issues that measures if the intend of the course is reached, and is a part of the data that head of study needs to ensure that the study programme is with the right content.

The change in course evaluation provides the teacher with a new dimension in evaluating course activities. Now the teacher can beforehand identify important issues, included in the course, which is to be evaluated. These issues are in the category of efficiency of specific learning activities, and are individual to every course. Some examples are evaluation of specific cases used in teaching a certain subject, a text book introduced, laboratory work, project work in the course or alignment between teaching and formative evaluation.

Toolbox:

The teacher is provided with a "inspiration toolbox", which consists of 9 different methods to evaluate (3).

Expectation letter:

Each student writes down their expectations to the course, based on what they have gathered of information from the curriculum or elsewhere. The teacher keeps the expectation letters and provides the students with them at the midterm evaluation, now the students can

reflect on their first expectations, what they have learned and what is to be changed if anything.

Course contract:

The contract is characterized by its commitment to the teacher as well to the students. The contract is drawn up by the teacher and students together, emphasizing their mutual expectations to the course, and each other. The contract typically links to various elements in the teaching situation, that is how teaching is organized, what types of instruction is to be included, the preparedness of the students, the extent to which students are expected to make presentations / participate actively, and so on. By course's mid-term contract may be used as a starting point for evaluation.

Questionnaire:

The including the topics to be evaluated: Student learning, Co-operation and commitment, Structure and teaching.

Interview and wall newspapers:

The students interview each other in pairs or threes from a widely formulated topic question, it could be "What is your personal learning outcomes of the course? Does it redeem your expectations, why or why not, what can be done better?" Each group creates a wall newspaper, including short formulations of the answers to the topic. Finally the wall newspapers are to be read by the course participants, and together with the teacher they reflect on the overall picture of the course.

Dialog between teacher and reference group:

The teacher and team chooses from the first day at the course, a group of students who will act as a reference group. The other students can give their feedback to the reference group, who will discuss the issues with the teacher.

Dialogue between teacher and selected students:

Used as a direct feedback tool right after a lesson. 2-3 students are selected to give the teacher a spontaneous and informal feedback on the lesson content and teaching.

Delphi method:

On a piece of paper the students individually write 3 great things about the course and 3 things that can be improved. Then all the papers circulated simultaneously in the same direction until they come back to the author. Every time a student receives a paper, he is to read the opinions and make a dash at them, he agrees in. Once the papers have been read and marked by all of the students, the result is a collection of statements concerning the teaching and a expression of how many students agrees in the individual statements.

After this team and teacher jointly discuss and reflect on the outcome.

1-minute paper:

In the last minutes of a lesson the students write their immediate and spontaneous reaction to teaching. The method can be used systematically after each teaching session or occasionally as needed. The teacher can for example ask the students to write what may be helpful for the teacher to gain knowledge of. For example do the students see the connection between the just completed lesson and the overall subject? Is the dissemination of material well-functioning? Is there an adequate interaction between teacher and student? Are there unresolved issues?

Essay Evaluation:

An expansion of the 1-minute paper, which invites students to a further reflection of contexts. Therefore, the method is best at the end of a course. If the students at the beginning of course have written down their expectations, the essay evaluation can be based on this.

Evaluation of a term:

The teachers involved in courses taught on the same semester, forms the semester team. The team has a joint responsibility in coordinating the different course learning activities in such a way that the technical issues taught, forms continuity in the term. The process of evaluating this is as follows:

- The first meeting of the semester team establishes the evaluation purpose and -fields
- The team coordinator presents the evaluation fields and process to the students
- The evaluation purpose, priorities and process is presented to the head of study within the first month.
- After the evaluation the semester coordinator is responsible for organizing and preparing a evaluation conclusion memo and present it to the head of study.
- Head of study and the semester coordinator jointly develop a action memo

How to engage:

Involvement ensures engagement. It is important that all of the course stakeholders are contributing to the course evaluation. The experience otherwise (and upon till now) is that the students loose interest in the evaluation procedure, the head of study looses a tool for improvement and the teacher a tool for reflection.

The following dialog based procedure, has been introduced, for evaluating the course Or any well-defined parts of the course:

- In one of the first lessons, the teacher proposes evaluation method (s) for the course. The teacher presents evaluation type and tracking method for course participants.
- Within the first month of the course, the teacher presents the evaluation method, the purpose, priorities and process, to the head of study.
- The Teacher conducts the evaluation; conclusion memorandum signed by the class representative and teacher are sent head of studies.
- After the course, the head of studies and teachers jointly develop action memo on the upcoming course development.

How to take action:

For both the evaluation of coursework, and evaluation of the terms, the head of study gathers the information or action points in a summary to the director of study. The given action points are included in the preparation of the courses for the next semester, and in all they draw the outlines of the course development wanted to ensure a dynamic and active study environment.

Evaluation of the evaluation procedure

The evaluation methods used during the past year, shows that the primary method chosen by the teachers is the questionnaire, with additional questions regarding specific course issues. A small number of teachers has been using different methods as the Delphi method, and responds positive to the personal outcome of this method. It is easier to discuss course issues with a set of student statements to set the scene.

The involvement of students is still a issue to be addressed, students respond is in average less than 30%, but fortunately these 30 % is very enthusiastic in giving qualified feedback to the teacher about the course and the involved learning activities.

There is still a work to be done regarding how to respond in an appropriate way to course issues, and how to ensure that action points are set in order to develop the course in a way that responds to the overall program development.

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Proposed framework for Transdisciplinary Product and Process Design Education

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ABSTRACT

Breakthrough products and services (e.g., iPhone, YouTube, Facebook) show us that products must do more than just “do the job”. They must “do the job” in an overwhelming, industry transforming way to overtake competitors. What can we learn from these successes and how could this change the way we teach our students? How can students be prepared to take an active part in the creation of the next breakthrough products and services in industry?

In this paper, we describe an initiative to create a transdisciplinary project learning environment by growing on many interdisciplinary experiences and building on previous multidisciplinary successes like MATI Montréal research-transfer center (www.matimtl.ca). It regroups three institutions in engineering, education and business to develop and study the use of technology in education. MATI houses an innovative ideation support systems lab called the Hybrid Ideation Space [1]. The proposed transdisciplinary framework will be part of MATI’s strategic objectives, under its collaborative product and process design initiative.

The proposed framework will:

- 1) Cultivate the design and innovation abilities of students in complex and realistic industry mentored projects.
- 2) Make students experiment the divergent points of view and expertise from different specialists involved in industrial product development.
- 3) Make students participate in the complete product development and production cycle multiple times. Develop a holistic view of project issues and impacts.
- 4) Build international academic relations so students can have true multinational, transdisciplinary project experiences.
- 5) Use the projects as a basis for design methodology and tools research to improve the project framework and transfer new acquired knowledge to industry.

KEYWORDS

Transdisciplinarity, complex projects, collaboration with industry, open ended problems.

TRANSFORMATION OF DESIGN PROJECTS IN INDUSTRY

Outsourcing has changed the industrial environment where students will work. Manufacturing knowledge and technical design expertise are no longer captive abilities as they are now transferred to independent suppliers. The difficulty is no longer how we can make a product, it has become what product should we be making. Successful new products and services provide solutions to very complex design problems to answer human needs. To achieve a virtually seamless product experience, design staff must constantly cross disciplinary boundaries.

“The user experience has to go through the whole end-to-end system, whether it’s desktop publishing or iTunes. It is all part of the end-to-end system. It is also the manufacturing. The supply chain. The marketing. The stores. “

John Sculley, ex-CEO Apple Computers

The product is no longer just a physical artefact. It has become a stream of intertwined experiences: brand image, interaction, communication, sharing, and content; each small part contributing to the success of the whole. Solving complex problems of this type requires the combination of many fields of expertise and is based on profound and integrated systems knowledge. This knowledge can come from many years of experience of one individual but can also come from a very efficient open collaboration between specialists. This collaboration extends far beyond the traditional engineering domain. The level of collaboration required is also far beyond working punctually with external collaborators from other disciplines. The level required is true transdisciplinary collaboration.

TRANSDISCIPLINARITY IN DESIGN EFFORTS

Complex “wicked” [2] problems do not only need to be solved but solutions must ensure long term sustainability of design choices. The problem solving approach needed to resolve complex issues must provide a wider view than what standard disciplinary problem solving methods offer. “Transdisciplinarity raises the question of not only problem solution but problem choice” [3]. The design solutions can no longer just be the result of standard technical problem solving but must take a much larger view including impact on society and ethical questions. Fundamental questions like : what to design, what not to design, why should we design this specific product and not another, what long term impact might this product have, is this impact justifiable, does this product only contribute to consumerism and finally can we design differently ? Students doing project work must be exposed as early as possible to these complex questions so they can prepare to answer them or be ready to transform the problem (the question) to get better solutions (answers).

Transdisciplinary projects can be differentiated from inter- or multidisciplinary efforts by a few features: “problem focus, evolving methodology and collaboration” [4], as detailed in Table 1.

Table 1
Transdisciplinary approach, taken from [4]

Features	Characteristics
Problem focus	<ul style="list-style-type: none"> ▪ Explicit intent to solve complex and multidimensional problems. ▪ Involves interface between humans and systems. ▪ Transdisciplinary problems are in the world and actual instead of in my head and conceptual.

Evolving methodology	<ul style="list-style-type: none"> ▪ Transdisciplinary work develops a common methodology that integrates different disciplinary methodologies into one.
Collaboration	<ul style="list-style-type: none"> ▪ Collaborative knowledge generation between project team, people affected by the project and all stakeholders.

TRANSDISCIPLINARY PROJECT FRAMEWORK

Different avenues have been used to foster collaborative work between product development disciplines in an academic context. Engineering CDIO projects, multidisciplinary projects inside and between schools, multidisciplinary curriculum to train “super designers” all include a push toward collaboration. Stanford University’s d.school, Aalto University and the upcoming EIT ICT labs are prime examples of the drive towards even greater collaboration between disciplines involved in product and process development.

Since 1999, École Polytechnique has engineering student capstone projects with the aerospace industry (CAMAQ projects) [5] and shown in Figure 2. Participating in the CDIO initiative has brought curriculum changes to extend this type of project. The goal is that students in all engineering disciplines will complete four projects covering all aspects of the design-build-implement-operate cycle.

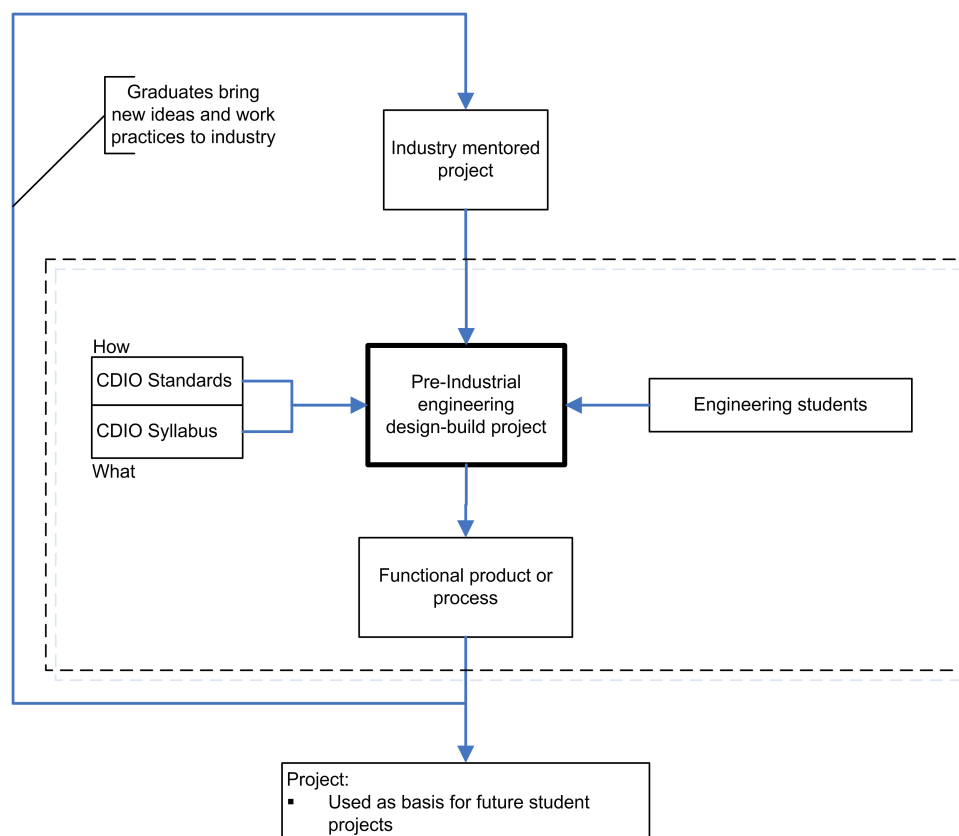


Figure 2. CAMAQ framework

To further improve this project vision, multidisciplinary projects were introduced in 2006 to integrate engineering students to collaborative teams including students from outside of engineering disciplines to work on a common project. The projects in this initiative have

slowly evolved from multidisciplinary teams to become functional transdisciplinary teams. This type of project work reproduces the challenges and opportunities of design work in professional product design teams without overwhelming the students with real economic pressures. They can then better concentrate on learning project work. Since 2006, over 200 engineering, 12 industrial design and 20 business students have discovered new ways of looking at products with the help of their teammates. Industrial mentors and students alike report that this project experience completely transformed their initial view of the product to be designed but even more that the transdisciplinary interaction has transformed their view of product design methods and efficient teamwork. From these positive experiences and the observation of missing elements in the student curriculum to improve project work, a framework is proposed to grow this initiative to another level.

In our proposed framework, three schools representing the major functions in product design activities are involved: École Polytechnique de Montréal (engineering), HEC Montréal (business school) and University of Montréal (industrial design) as shown in Figure 3. The CDIO standards and syllabus provide a solid backbone for this framework. Disciplines outside engineering involved in the framework will apply the CDIO concepts to this project. This may be a first and possibly an interesting development for the CDIO initiative. The extension of the CDIO standards and syllabus from engineering to other product design related disciplines will at first serve to develop integrated curriculum and assessment tools.

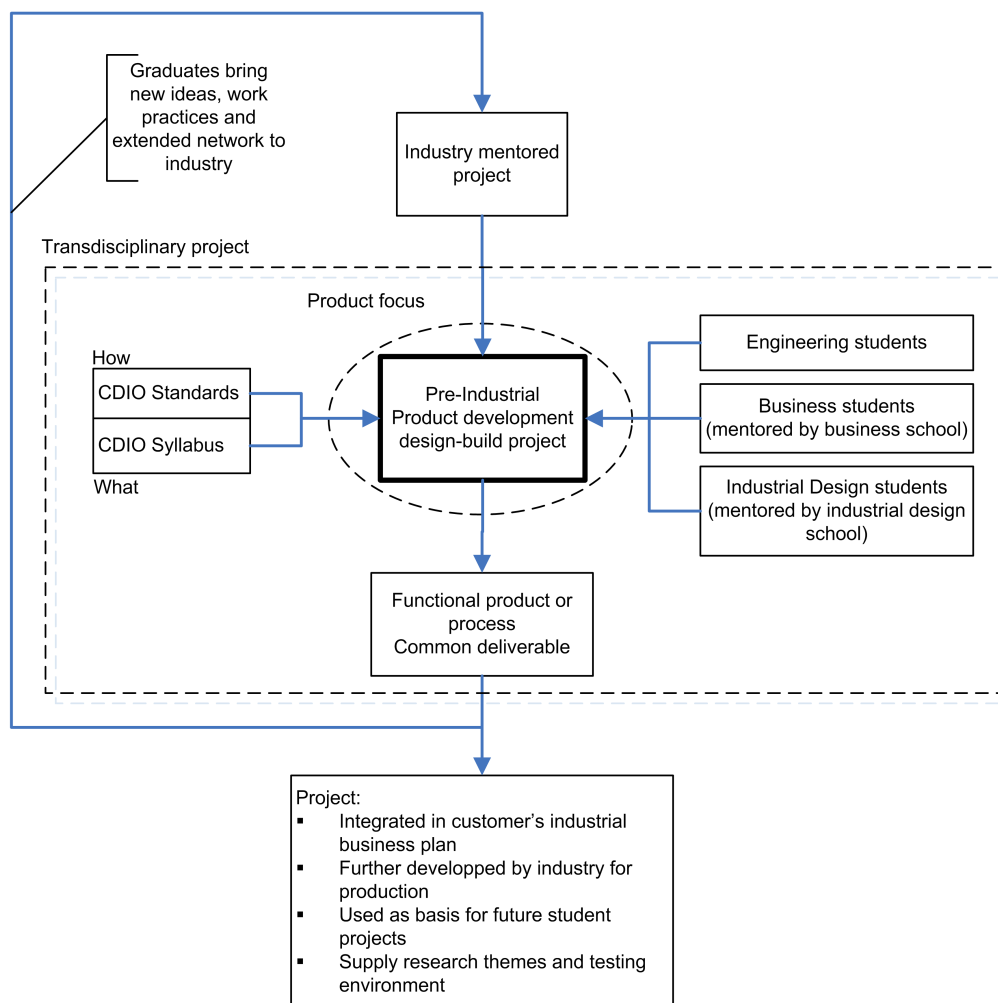


Figure 3. Proposed Framework

The framework proposes activities surrounding a central industry mentored development project for graduate and undergraduate studies. Design activities across multiple disciplines

align more easily when a common goal with common deliverables is identified from the start. A common goal does not mean a clear goal however. Projects are selected to be open ended design problems with no clear and evident solution. It is in this type of problems that a transdisciplinary team truly shines. The product centric view of transdisciplinary student capstone projects generates real advantages for all stakeholders as shown in Table 2. The proposed framework will structure and develop these observed advantages in existing projects to generate a wider industry base for mentoring future projects.

Table 2
Advantages of proposed framework

Project wide	
Innovative solutions to complex problems from transdisciplinary decision making.	
Sector	Disciplinary
Industry <ul style="list-style-type: none"> ▪ Direct university contact with project mentoring. ▪ Technology transfer of developed projects. ▪ Access to the results of 6000-8000 hours of development team efforts. Research <ul style="list-style-type: none"> ▪ Industry needs based research ▪ Technology development and licensing. ▪ Access to in-context teams for concept testing of development processes or project tools. Training <ul style="list-style-type: none"> ▪ Train students better prepared for project work. ▪ Modify training curriculum through in-situ project observation. ▪ Develop better university-industry networks. 	Engineering <ul style="list-style-type: none"> ▪ Confront complex open ended problems with multiple solutions and social components. ▪ Answer "Why develop this product" essential in sustainability issues. Industrial design <ul style="list-style-type: none"> ▪ Learn to interact with technical issues early on and throughout the project ▪ Learn to interact with business issues early on and throughout the project ▪ Introduce and defend the user-centric approach in the project Business <ul style="list-style-type: none"> ▪ Work from start to finish of the project with a technical development team. ▪ Follow through all project steps up to manufacturing of prototypes and possible market introduction.
In the Future	
Students are to experience multinational project collaboration.	

Through this in context experience of project work dedicated to deliver a single integrated product, the knowledge barriers and conflicts between disciplines appear quickly. The process used to solve complex problems, conflicting issues and build consensus in the project team break the disciplinary boundaries and with time can achieve true transdisciplinary project work. Once true collaboration is achieved, successful seamless product design experiences can emerge.

To date, one of the most interesting outcomes of these transdisciplinary projects is to have one of the student vehicle projects brought to market. The student generated market, technical, product design and financial analysis permitted the start-up company to view its product in a new light, redefine it and convince investors to finance professional industrial R&D. The commercial product will be presented publicly in June 2011, one year after the end of the student project.

THE FRAMEWORK AND ACADEMIC RESEARCH

The student projects also generate academic research subjects. The close proximity of this framework's transdisciplinary projects and the industrial practice of product design creates opportunities to observe, test and develop new product design practices. The involvement of MATI Montréal in educational research and technology supported education tools make it uniquely positioned to support this framework. Existing multidisciplinary research efforts in distance collaboration tools, e-learning and educational portfolio can be applied in a project context as multinational project collaboration tools, electronic support for team information archiving and knowledge management.

The immersive sketching and model making electronic tools developed by the MATI's Hybridlab is a great example of the possibilities. This installation facilitates collaboration between multinational design groups by providing a single virtual ideation space that can be shared to collaboratively generate full scale sketches in an immersive space. The installation presently connects 5 universities in Canada, Germany, Switzerland and the USA. Other supported research subjects and activities include:

- Learn how to improve collaborative work environments and team dynamics.
- Develop new tools to support collaborative project work (local or remote).
- Study creativity and innovation in project teams (fully equipped observation room).
- Work on sustainable development decision tools for project work.
- Propose school curriculum modifications based on student's difficulties observed in a project context.
- Transfer acquired knowledge on teamwork and collaboration tools to industry.
- Supply research services to industry to test new project management methodologies.
- Use international academic contacts to create multinational student project teams.

IMPLEMENTING PROPOSED FRAMEWORK

Formalizing and expanding the undergraduate transdisciplinary projects across École Polytechnique is the first step to continue building relations with industry. New sectors selected for transdisciplinary project proposals include aeronautics, electronics and software, building infrastructure and medical devices.

In parallel, MATI Montréal will support a transdisciplinary advisory team, 3 representatives from each school involved in the framework, to build a new graduate program. The advisory team will:

- Meet with local and international innovators in product development (Cirque du Soleil, Bombardier, RIM, Pratt&Whitney, Sid Lee, Cascades, Virgin, Google, Apple, etc...)
- Combine and build internal knowledge on innovation (engineering, marketing, philosophy, history) to integrate in program proposal.

- Prepare small group discussion sessions with industry to build and assess program proposals in a continuous improvement approach.
- Test and use the collaborative tools and environment that will be later proposed to students.

From this research and field studies the advisory team will propose a microstudy program (15 credits) planned for September 2012. It could expand to a study program (30 credits) and finally a 45 credit masters program planned for 2014.

CONCLUSION

Based on observations made in industry and during transdisciplinary student projects since 2006, the need to further prepare students for complex project work was felt. To achieve this, a framework linking 3 schools involved in product and process design activities is proposed. This framework defines the project environment where students from École Polytechnique de Montréal (engineering), University of Montreal (industrial design) and HEC Montréal (business) will collaborate. A multidisciplinary research group, MATI Montréal already involved with all partners, will be the central hub to build this framework to a master's program by 2014.

The proposed framework defines a project environment where students develop product and processes for industry using an open ended mandate. Solutions to be developed must both extend the students acquired knowledge and abilities but also challenge the industrial mentor's view of its proposed project. The transdisciplinary structure of the student teams permits this broad view of design problems by combining knowledge from different fields into a single project outcome.

The involvement of MATI Montréal for academic research in project work environments including team dynamics and collaboration tools provides opportunities to further improve student training and develop innovative design methodology for industry. International academic and industrial partners are welcomed to build this framework so multinational transdisciplinary student projects can become a reality.

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Biographical Information

Daniel Spooner is associate professor at École Polytechnique de Montréal. He also teaches at Université de Montréal's School of Industrial Design. In the last 18 years, he has lead development teams for more than 70 products in the transport, consumer, medical, and telecommunication industries. He operates his own product design and engineering consulting firm involved in complex system design. He contributes actively to the CDIO capstone project initiative at École Polytechnique since 2006.

Jacques Raynauld is full professor at HEC Montréal where he holds the Chair on Teaching and Learning in Management Education. He is also the director of MATI Montréal and leads a large research/transfer initiative on integrated curriculum design, accreditation processes and learning assessment portfolio tools.

After almost twenty years as a practising industrial designer, providing services to clients in most of Québec's industrial sectors, Philippe Lalande is now a professor and researcher at the School of Industrial Design of the Université de Montréal. Exploring ways of including digital technologies within the academic program of the School, his research also spans various subjects related to the application of 3D modelling techniques to the design process, in particular Rapid Prototyping. He is the director of Formlab, a research facility dedicated to the development of physical and virtual modelling techniques and teaches courses related to this area of specialization as well as the Professional Practice of Design. Since June 2009, Philippe Lalande is Chair of the School of Industrial Design.

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Course on Advanced Analytical Chemistry and Chromatography

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Abstract

Methods of analytical chemistry constitute an integral part of decision making in chemical research, and students must master a high degree of knowledge, in order to perform reliable analysis. At DTU departments of chemistry it was thus decided to develop a course that was attractive to master students of different direction of studies, to ph.d. students and to professionals that need an update of their current state of skills and knowledge. A course of 10 ECTS points was devised with the purpose of introducing students to analytical chemistry and chromatography with the aim of including theory, exercises, presentations, practices and procedures, and reporting. After the course the students are able to perform the tasks of analytical laboratories at the level of laboratory leader. Subjects of quality assurance are difficult to make interesting to the students but in this course exercises are included that encourage students in a competitive manner to demonstrate their laboratory skills under the conditions of method validation. This tutorial procedure proved successful in the sense that students were able to understand and report the results according to standard operations procedures. The students are provided with detailed oral instructions and limited instructions in writing thus allowing them to conceive their own approach to designing the experimental setup in close collaboration with teachers. There are several teachers of different DTU departments affiliated to the course allowing the students to meet the foremost experts of technology in specialized areas of chemical analysis and chromatography. Laboratory exercises are performed at different laboratories that provide access to high-quality apparatus. The students are evaluated by a report of exercises extending to 2½ ECTS and an oral examination in the remaining part of the syllabus covering 7.5 ECTS.

Course Structure

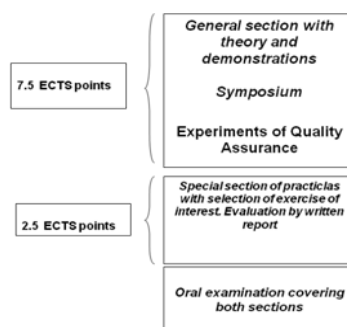


Figure 1. The course on Analysis and Chromatography (DTU 26316) covers 10 points distributed in two main sections. In the first section of theory and problem solving the students are introduced to the theory that allows them to perform presentations at a symposium. In the special section experiments are performed.

Conceive: Based on the section of theory, students may suggest methods of reliable chemical analysis.

Design: Analytical chemistry is characterized by hyphenating several types of apparatus that allows specialized types of analysis. The design of the manifold or experimental setup is important to automation and reliable analysis.

Implement: The experiments are performed in several different laboratories in departments of DTU where the students implement designed methods under the supervision of teachers.

Operate: In order to ensure applicability to real measurements, the students perform several exercises using advanced apparatus that must be subjected to maintenance and safety regulations. The results obtained should be monitored by methods of quality assurance.

In figure is shown an example of results obtained by students performing exercises in part two of the course.

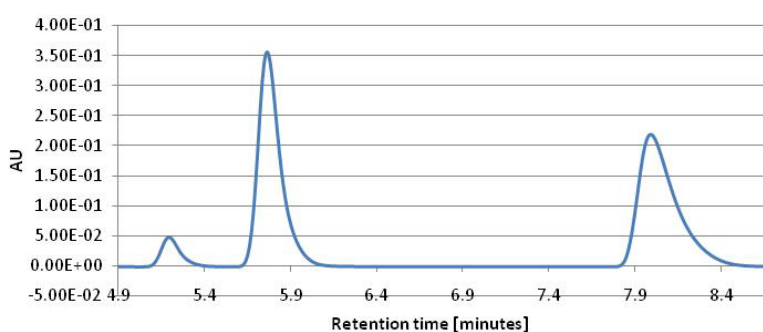


Figure 2. Advanced results obtained by students at course 26316, special section. 5 Isocratic HPLC separation of mixture of R- and S trans-stilbene oxide at 10 mL/min on a 250x4.6 mm Chiralcel OD-H column with 10 vol% 2-propanol and 90 vol% hexane. The PDA detector measured absorbance at 254 nm. First peak: 5.53 area%; second peak: 46.6 area %; third peak: 47.87 area%.

Conclusion

The course was attended by between 40 and 55 students within the first three years of implementation. Almost all the students who attended the final oral examination passed the course. More than 50 % of the students found they learned a lot but found the workload to be relatively high.

FIRST YEAR EXPERIENCE OF CDIO ADOPTION INTO AN INFORMATION TECHNOLOGY PROGRAM

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ABSTRACT

The Faculty of Information Technology, University of Science has been selected and supported financially by the Vietnam National University – Ho Chi Minh to adopt CDIO into its program. The 7-year CDIO adoption project has been set up and started to improve the teaching and learning quality at the school. However, it is a big challenge due to the fact that the adoption process will be carried out for the whole school with 4 departments, over 2000 students, and 150 faculty members. Although all departments are IT-related, their teaching and learning styles are a bit different. Two are research-oriented and the others are industry-oriented. In addition, although CDIO has been introduced for over 10 years now, the number of documents on the CDIO website to instruct you how to adopt CDIO into school programs are very limited. The documents tell you very briefly and generally about the adoption process. Thus, as a newcomer, we found it quite difficult to follow. This paper describes steps that the school has gone through and difficulties encountered during the 1st year of the process. After one year adoption, we have built up a new CDIO-based learning outcomes and the CDIO-based curriculum structure to an existing program. We also did self evaluation based on the rubrics analysis within the 1st 4 months and did it again at the end of the 1st year to see the progress.

KEYWORDS

CDIO adoption, program learning outcomes, CDIO-based curriculum structure

INTRODUCTION

In December 2009, the Faculty of Information Technology (FIT) has been assessed externally by the ASEAN University Network (AUN-QA) [2] at program level. Even though the

assessment results showed good on 12 criteria (including 71 sub-criteria), equivalent to other programs in the ASEAN region, there are remaining problems that need to be improved. The 2 biggest problems are the program learning outcomes and the curriculum structure.

The existing FIT learning outcomes and the curriculum structure have been built based on the framework proposed by the Ministry of Education and Training, the references of ACM/IEEE training program and the curriculum of well-known universities, such as MIT and Stanford. However, the process of building the learning outcomes and the curriculum structure is based on personal experience and skills rather than a methodology. In particular, the learning outcomes were listed only at one level, which sound very general. Thus, when reading the CDIO syllabus and the process of adoption, integrating personal, interpersonal and CDIO skills into the curriculum [3, 4, 5, 6, 7], we realized that it is the methodology to improve the teaching and learning quality at the FIT.

The CDIO approach is used to improve the teaching and learning quality in engineering education introduced by a group of 4 universities, including MIT in the US, Chalmers, LiU, and KTH in Sweden [4, 7]. Currently, there are over 50 universities from all over the world which are participating into the collaboration.

In 2010, the Vietnam National University – Ho Chi Minh decided to select 2 programs to adopt CDIO as pilot programs before carrying out on all of the technical and engineering schools. FIT was selected as one of them. The project will run for a total of 7 years to carry out the whole process of adoption and improvements after a couple of graduation batches. It is a big opportunity for FIT to reform its teaching and learning program based on a well-known methodology. The school has decided to form up a CDIO task force to manage and control the project. In the first year of adoption, FIT planned to revise and update the learning outcomes and the curriculum structure of the school based on CDIO. The participating groups are listed as follows:

1. Managing board: in charge of managing and monitoring the pilot program
 - a. The Vice Rector of the university
 - b. The Dean of the Faculty
 - c. The manager of the CDIO pilot program (Vice Dean)
 - d. Secretaries
2. The main CDIO groups:
 - a. Group 1: in charge of building the new CDIO-based program learning outcomes of the faculty.
 - b. Group 2: in charge of building the surveys
 - c. Group 3: in charge of analyzing the surveys
 - d. Group 4: in charge of adopting the current curriculum structure to reflect the CDIO skills and the results from stakeholders' surveys. There are 4 small groups. Each consists of leaders of each program tracks of the faculty.
 - e. Group 5: in charge of developing pilot courses with design-build experiences. Four courses were selected for pilot implementation. There are 4 small groups. Each consists of all lecturers/professors who have experiences in teaching the selected courses.
3. The faculty scientific committee: in charge of verifying, approving and making recommendations to the development of the new CDIO-based learning outcomes and the faculty curriculum structure.
4. Others: all lecturers, alumni, students and industrial partners

The next section describes the existing learning outcomes and curriculum structure at FIT. Then, the CDIO process for the first year of adoption will be discussed in details in the section after that. The new CDIO-based learning outcomes are then discussed. It is followed by the curriculum structure section where the process and difficulties are mentioned. Another

section will describe the self-evaluation based on rubrics in the first 4 months of adoption and after 1 year. Finally, the conclusion and remarks close the paper.

THE EXISTING LEARNING OUTCOMES AND CURRICULUM STRUCTURE

Before applying CDIO, the FIT has the following learning outcomes, listed in Table 1. The learning outcomes describe generally all the main aspects that a FIT student will achieve when he or she graduates. However, the existing learning outcomes are not specific enough to integrate into the curriculum structure or course syllabi.

Table 1
The FIT learning outcomes before adopting CDIO [1]

A	Understanding of the country's current state, responsibility, and ethics
B	Know how to apply soft skills
C	Ability of professional development and inheritability
D	Ability to apply basic and academic knowledge
E	Ability to analyze, design and implement computing systems
F	Ability to test, operating, evaluating, and maintain computing systems
G	Ability to use computer-based supporting tools

In addition, the learning outcome development was based on personal experience and skills with the reference from other well-known universities and resources. Those learning outcomes have not been verified by any stakeholders except the Board of Deans and some experienced lecturers.

Besides the learning outcomes, the curriculum structure has similar problems. The school has revised and improved the curriculum structure every 3 years. However, the process of building and improving the curriculum structure is also based on personal experience of the teaching staffs and the Board of Deans. It did not follow any formal methodology. Thus, the curriculum structure does not guarantee to cover all the aspects of the school learning outcomes, to avoid the overlapping between courses and to have a smooth flow of the courses along the 4 years of the program.

Figure 1 shows an overview of the existing curriculum structure with the course names. FIT has been carrying out the teaching and learning program based on the mission and vision of the school and the framework of 140-credit program proposed by the Ministry of Training and Education. The program covers from the general knowledge, fundamental professional knowledge and major knowledge to graduation.

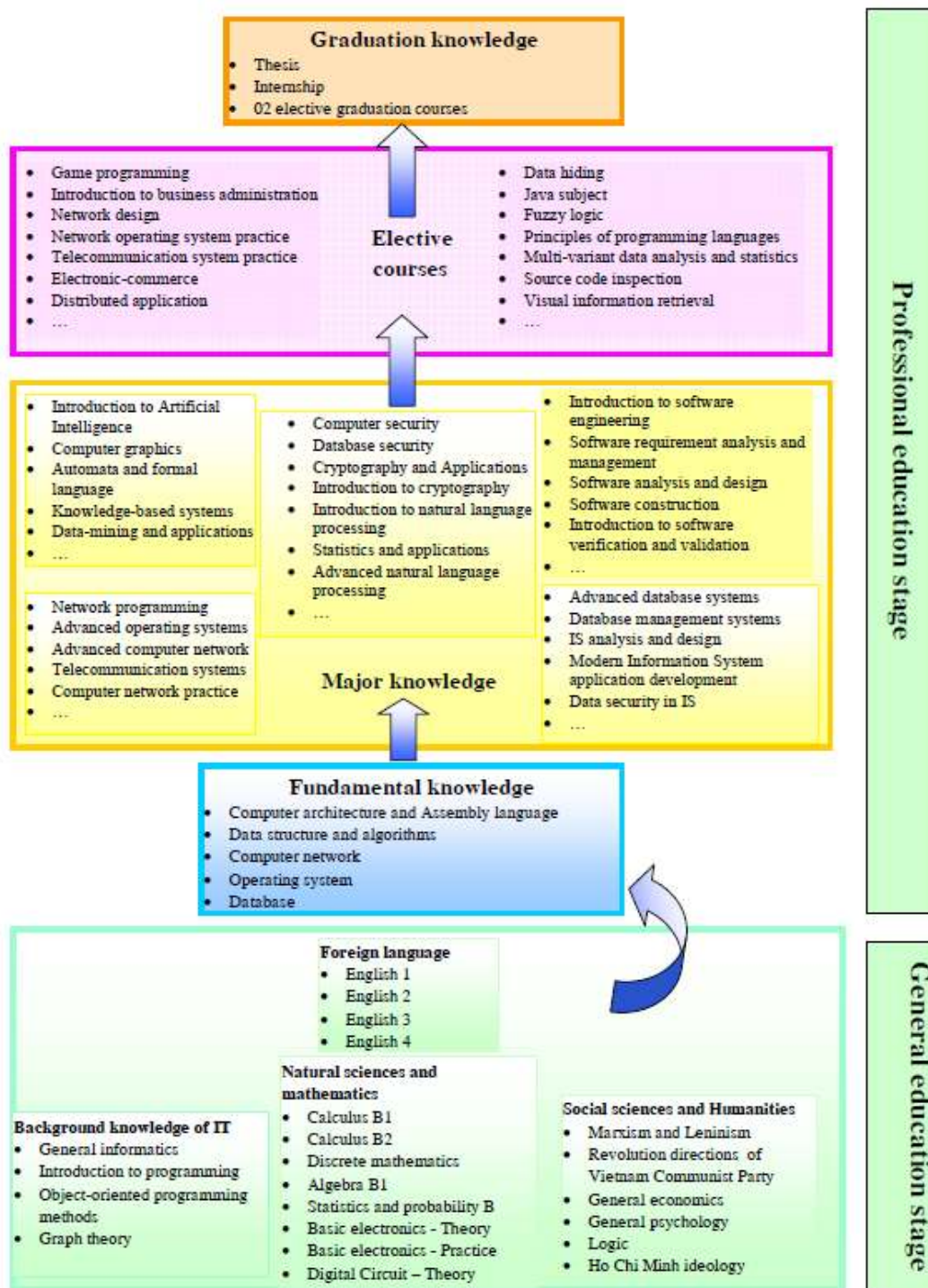


Figure 1. An overview of the existing FIT curriculum structure [1]

CDIO ADOPTION: THE PROCESS FOR THE FIRST YEAR

The whole project will last for 7 years. In the first year, the main objective is to build a new CDIO-based learning outcomes and curriculum structure based on the existing one. In addition, a pilot program of integrating personal, interpersonal and CDIO skills into 4 courses

is carried out. Figure 2 shows the process of forming up the new learning outcomes and curriculum structure for FIT.

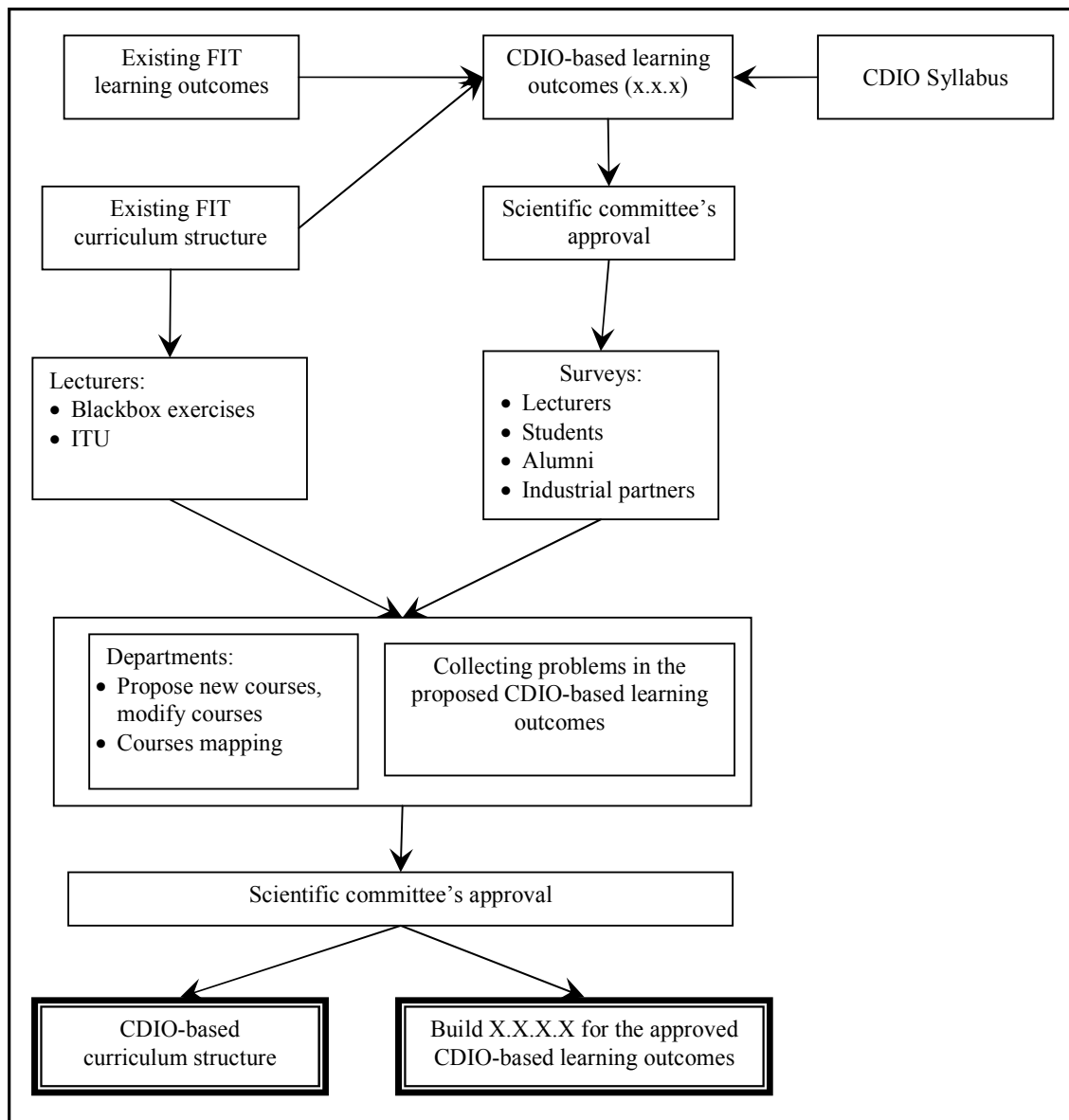


Figure 2. The process of building new CDIO-based learning outcomes and curriculum structure

Step 1: FIT collects the existing learning outcomes A-G, curriculum structure and the CDIO syllabus.

Step 2: Based on the existing FIT learning outcome, the curriculum structure and the CDIO syllabus, the CDIO task force proposes the first draft version based on the nature of teaching and learning of FIT. The first version is built up to level x.x.x

Step 3: Present and discuss the learning outcomes in front of the Scientific Committee. The committee verifies and approves the learning outcome version 1, which is ready for surveys.

Step 4: Doing the surveys for all stakeholders, including staff members, students, alumni and industrial partners. In this step, we particularly concentrate on the survey outputs of the staff members and industrial partners. In addition to the surveys on learning outcomes, we ask lecturers to do the ITU and blackbox exercises for all the courses in the program and

mapping with the learning outcome at level 3. It is the basis for forming up the new CDIO-based curriculum structure.

Step 5: Collecting the outputs and proposing the new CDIO-based learning outcomes and curriculum structure of the FIT.

Step 6: Scientific committee and Heads of Departments will revise, discuss and give final approval.

Step 7: The final version of the new CDIO-based learning outcomes and the new CDIO-based curriculum structure for the FIT.

CDIO-BASED LEARNING OUTCOMES

Based on the current FIT learning outcomes and the nature of teaching and learning of the school, the CDIO adoption team has investigated the CDIO syllabus and picked up the related topics up to level x.x.x. The list has also been modified in order to reflect the group of learning outcomes that FIT focuses. Figure 1 illustrates the FIT CDIO-based learning outcomes at level x.x.

Learning outcomes of the Faculty of Information Technology (HCMUS)			
L1	L2	L3	
1			Fundamental knowledge
1	1		Fundamental knowledge of basic sciences
1	2		Fundamental technical knowledge of computer science
1	3		Advanced technical knowledge of computer science
2			Professional skills and development
2	1		Analytical reasoning and problem solving
2	2		Experimentation, Investigation and knowledge discovery
2	3		System thinking
2	4		Self-study and life-long learning
2	5		Project management
3			Context, responsibility, and ethics
3	1		External, social, economical and environmental context
3	2		Enterprise and business context
3	3		Ethics, responsibility and core personal values
4			Personal and inter-personal skills (soft skills)
4	1		Personal characteristics
4	2		Teamwork
4	3		Communications
4	4		Foreign language skills
5			Conceiving, analyzing, designing and implementing computing systems
5	1		Supporting tools and technologies
5	2		Requirements
5	3		Design and formulation
5	4		Implementation
6			Verification, validation, operation, maintenance and evolution computing systems
6	1		Verification and validation
6	2		Operation and maintenance
6	3		Evolution and disposal

Figure 3. The FIT CDIO-based Learning Outcomes

In the new FIT CDIO-based learning outcomes, section 1 still contains the fundamental knowledge. Section 2 mentions the professional skills and development. Context, responsibility and ethics are listed in section 3. Section 4 covers the personal, interpersonal

skills. Instead of keeping CDIO skills in one section as in CDIO syllabus, we decided to break it into 2 sections, one is for conceiving, analyzing, designing and implementing computer systems and the other one takes care the verification, validation, operation, maintenance and evolution of the system. The new organization of the sections is based on the nature of the teaching and learning at FIT.

The new CDIO-based learning outcomes have been reviewed by the scientific committee and gone through a list of surveys from all stakeholders, including staff members, alumni, and industrial partners. The output of the surveys and revision are then discussed in more details in the scientific committee before finalizing the new CDIO-based learning outcomes. An example of the result for the surveys from alumni and industrial partners on the new CDIO-based learning outcomes is shown in Figure 4.

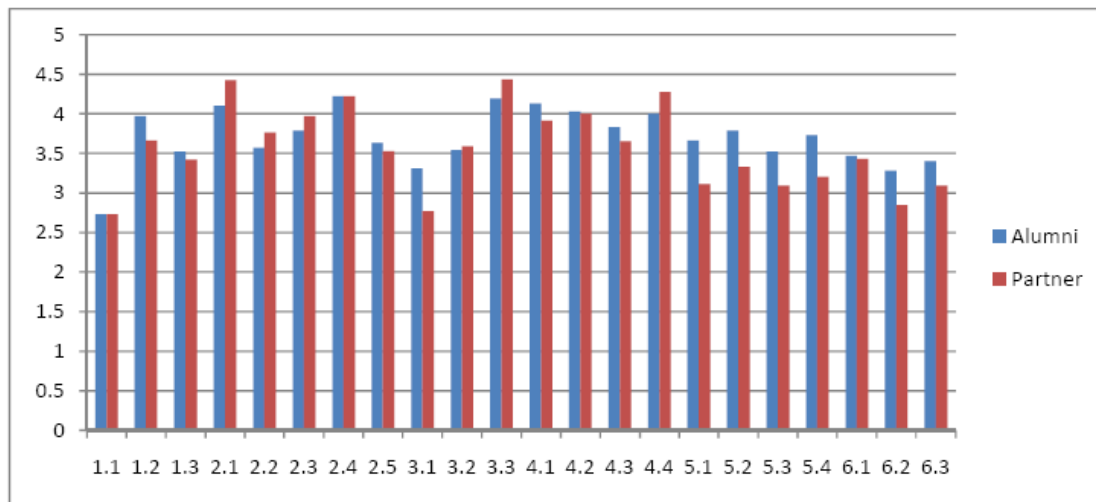


Figure 4. The expectation from the alumni and the industrial partners

CDIO-BASED CURRICULUM STRUCTURE

Currently, the existing FTI curriculum has 140 credits, including fundamental knowledge, professional knowledge and graduation. However, when mapping and comparing with the new CDIO-based learning outcomes, we found out that there are a lot of things that need to be improved and changed.

Lecturers are asked to perform the ITU mappings and blackbox exercises for all courses that he or she has taught. The work has shown some broken links in the curriculum structure and some overlaps in the courses. The Head of Departments and the Scientific Committee are responsible for resolving these problems. There are some possible solutions:

- Open a new course to cover the missing parts or broken links
- Modify the syllabi of courses to guarantee the connection between courses and avoid the overlap. Also, it is built to guarantee the level contribution of the course to the learning outcomes.
- Scientific Committee is the last to revise and approve the outputs.

RUBRICS

During the process of CDIO adoption, FIT is aware of taking self-evaluation based on the rubrics of 12 criteria provided by the organization. At the 4th month of CDIO adoption, we have carried out an initial self-assessment as in Table 2. In this table, most of the criteria are rated as the lowest level where there is nothing much in the school relating to CDIO, except the awareness of all staff members and students about the starting of CDIO adoption.

Table 2
Rubrics self-evaluation in the first 4 months of CDIO adoption

	CDIO STANDARD	EVIDENCE OF COMPLIANCE	RATING
1.	CDIO as Context	There is an agreement among faculty members that the CDIO principle is important and the basis for the program reform.	1
2.	CDIO Syllabus	We plan to adapt our current learning outcomes to the CDIO syllabus	1.5
3.	Integrated Curriculum	We started to have some awareness of CDIO principles. We have plans to carry out workshops on evaluating the current curriculum, learning outcomes with the CDIO principles	0.5
4.	Introduction to Engineering	There is no introductory course for the whole program. There is a similar course for a couple of program tracks but not for all.	0
5.	Design-Build Experiences	There are few design-implement courses in the current program. However, they are not planned to link together.	1
6.	Engineering Workspaces	Workspaces are inappropriate to support design-implement activities.	0
7.	Integrated Learning Experiences	There is a plan to carry out an evaluation of current courses on personal, interpersonal and CDIO skills.	0.5
8.	Active Learning	We are aware of the need of active-learning in the courses. Some courses have applied active learning methodology but still based on lecturers' experience.	0.5
9.	Enhancement of Faculty CDIO Skills	Young lecturers are asked to take part in professional courses to improve skills.	0.5
10.	Enhancement of Faculty Teaching Skills	All lecturers have to study and pass a course on teaching skills. Each year, there is a workshop for lecturers to discuss about the teaching skills and methodology.	0.5
11.	Learning Assessment	There are assessments on personal, interpersonal and CDIO skills, but they are not detailed enough to evaluate all the aspects of	1

		the CDIO principles.	
12.	Program Evaluation	A program evaluation has been done a couple of times now by the external people. It shows where we are and what we should do to improve.	1

After a year of adopting, mainly dealing with the FIT learning outcomes and curriculum structure, Table 3 shows another self-evaluation at the end of the year. During the time of building the learning outcomes and the curriculum, there has been a pilot implementation of 4 courses to integrate personal, interpersonal and CDIO skills.

Table 3.
Rubrics self-evaluation after 1 year of CDIO adoption

	CDIO STANDARD	EVIDENCE OF COMPLIANCE	RATING
1.	CDIO as Context	CDIO was accepted as part of the program reform plan. New CDIO-based curriculum has been approved. 4 courses have been revised to integrate personal, interpersonal and CDIO skills.	2
2.	CDIO Syllabus	The CDIO-based learning outcomes have been introduced in an alignment with the mission, vision and the specifications from the Ministry. The new CDIO-based learning outcomes were validated by the stakeholders.	3
3.	Integrated Curriculum	Curriculum has been re-designed to integrate personal, interpersonal and CDIO skills. Courses have been revised to ensure the smooth link between courses along the 4-year training. The first 4 existing course syllabi are adopted to integrate personal, interpersonal and CDIO skills. There is a plan to run these new syllabi in the next semester.	1.5
4.	Introduction to Engineering	The plan of adding a new introductory course was submitted to the university for approval.	1
5.	Design-Build Experiences	There is a plan for all first year students to take the introductory course. There is plan to arrange the courses so that the students can take basic and advanced design-implement courses in their later years.	2
6.	Engineering Workspaces	There is a plan to re-design an existing lab and equip it to support the design-implement activities.	1
7.	Integrated Learning Experiences	All the courses have been evaluated to find out the missing personal, interpersonal and CDIO skills. The first 4 courses have been adopted to reflect the CDIO principles.	1.5
8.	Active Learning	We are aware of the need of active-learning in the courses. Some courses have applied active learning methodology but still based on lecturers'	0.5

		experience.	
9.	Enhancement of Faculty CDIO Skills	Young lecturers are asked to take part in professional courses to improve skills.	0.5
10.	Enhancement of Faculty Teaching Skills	All lecturers have to study and pass a course on teaching skills. Each year, there is a workshop for lecturers to discuss about the teaching skills and methodology. There is annual plan for surveying and teaching lecturers about the implementation the new CDIO-based syllabus.	1
11.	Learning Assessment	There are assessments on personal, interpersonal and CDIO skills, but they are not detailed enough to evaluate all the aspects of the CDIO principles.	1
12.	Program Evaluation	A program evaluation has been done a couple of times now by the external people. It shows where we are and what we should do to improve.	1

CONCLUSION

After adopting CDIO for over a year, we have built a new FIT CDIO-based learning outcomes and curriculum structure. They are the basis for the quality improvement of teaching and learning at the University of Science, Vietnam National University – Ho Chi Minh in the coming years. Although the project is still ongoing, the positive effects have been seen by many stakeholders. We have also formed up a detailed process of how to build a new CDIO-based learning outcomes and curriculum structure based on the existing one. Especially, we have done rubrics self-assessment for a couple of times, which helps us much in identifying where we are and what we will do next. In short, we have found that the CDIO methodology is very suitable to apply into the existing program at FIT to improve quality of teaching and learning. The CDIO syllabus and processes are highly valuable for the improvement process at the school. We have also learnt a lot in building up a high-quality teaching and learning program based on the methodology provided by CDIO organization.

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INTERDISCIPLINARY CASE-BASED TEACHING OF ENGINEERING GEOSCIENCES AND GEOTECHNICS

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ABSTRACT

The complete restructuring of the 4-year Professional Bachelor programme in Arctic Technology at the Technical University of Denmark in 2007 has provided the perfect framework for implementing CDIO-based courses with focus on a holistic and interdisciplinary approach.

In this paper we present our experiences over four years teaching one such course, *11821 Site Investigations*. The goal is to teach the students to conduct site investigations in connection with construction work in arctic areas. It covers technical skills and competences from several different branches of engineering in an interdisciplinary course. Course elements comprise the understanding of relevant geological processes and deposits, tools to examine and map these deposits, as well as the use of Global Navigation Satellite Systems (GNSS) and Geographical Information Systems (GIS) to collect and organize spatial information. Environmental aspects and cultural heritage screenings are also covered as well as group work and report writing. The course is constructed around a real world case, e.g. the construction of a specific road segment, and the students have to produce a realistic site investigation report based on field and laboratory investigations as well as theoretical considerations.

The interdisciplinary structure of the course combined with the real-world case and just-in-time teaching applied has resulted in more motivated and hard working students, and as teachers we receive better and more interesting reports to read. However, the interdisciplinary and practically oriented nature of the course poses special demands on teachers and instructors. Among these are more complex coordination among course elements, and difficult adaption of the curriculum.

Based on written and oral feedback and our own teaching experience, we conclude that the new course form is an efficient and challenging way to teach engineering with good learning outcome over a broad spectrum of the CDIO syllabus.

KEYWORDS

Geoscience teaching, real-world case, interdisciplinary, personal and interpersonal competences, just-in-time teaching.

INTRODUCTION

Arctic Technology is a 4-year Professional Bachelor programme at the Technical University of Denmark (DTU). The programme is special in many ways; primarily because the first 1½ years of the education, the students live in Greenland, where they study at the DTU micro-campus at the Building and Construction School in Sisimiut. Since most teachers come to Sisimiut from Denmark to teach the students for periods of typically 1-3 weeks, courses have to be taught intensively, one course/subject at a time, rather than in parallel as is the practice at the main DTU Lyngby campus in Copenhagen.

These boundary conditions have supplied perfect framework for implementing CDIO based courses, when the education was completely restructured in 2007 [1]. The restructuring allowed us to change the focus from mainly core scientific and technical knowledge to a holistic and interdisciplinary approach focussing also on the personal, professional and interpersonal skills.

In this paper, we present our experiences obtained over four years of teaching the course *11821 Site Investigations* with a case-based, interdisciplinary, hands-on and just-in-time teaching (i.e. lectures are given when they are needed for the students to continue with the case, thus assuring they are highly motivated for learning) approach.

BACKGROUND

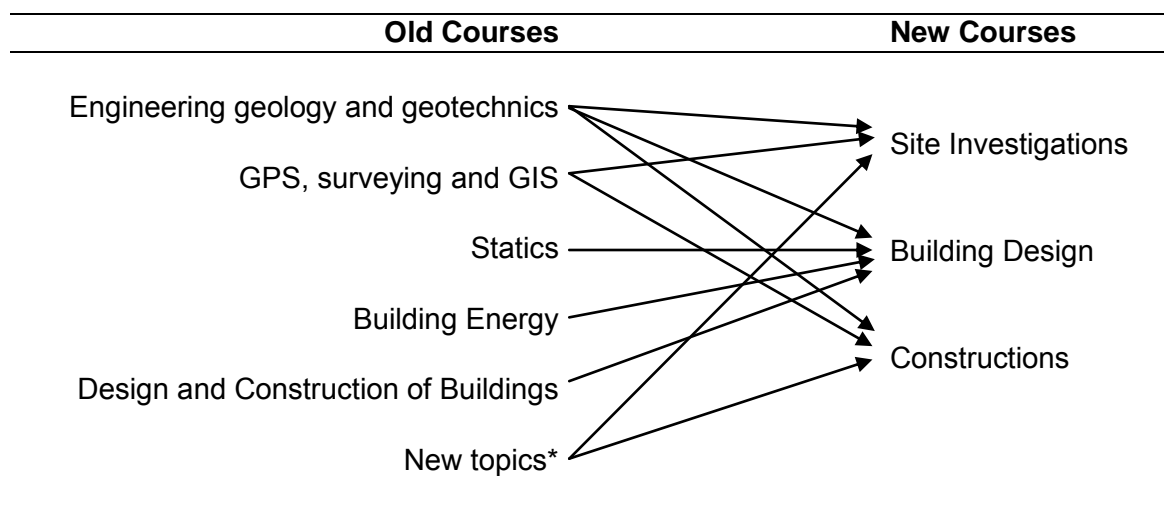
Previous to 2007, courses given at the Greenland campus were small intensive courses of 2-3 weeks duration; or longer courses split up into teaching sequences of 1-2 weeks distributed over the 3 semesters. The courses were organized and based on subject matter and professional content. Typically one teacher was in charge of and teaching each individual (part of a) course.

The reason for restructuring the curriculum was the study habits of the Greenlandic students, which were not suitable for the standard way of teaching at DTU. The students had a low activity in class, often did not show up and were accordingly in danger of dropping out – not because of academic skills but low engagement.

With the restructuring of the education [1], focus was put on producing an active learning environment initiating high motivation based on real-world cases. Therefore most of the new courses were implemented as “composite courses” – i.e. large interdisciplinary courses organised by teacher teams with teachers from all the fields of engineering involved in a course. Experts from the teacher team are present in turn, organising field work and giving lectures comprising all technical and professional elements necessary to solve the problems encountered during the work with the case. The students work in fixed groups during a course, and the students are assessed partly on individual work during the course and partly on the group report handed in at the end of a course.

This resulted in a major reorganization of courses and course elements as exemplified in Table 1 for courses related to geosciences. The focus has therefore changed from the subject of pure knowledge and technical skills to the objective of producing a certain outcome, e.g. a site investigation report, a proper foundation design, or a properly dimensioned road embankment.

Table 1
Example of relationship between old and new courses



*) Environmental screening and cultural heritage screening was introduced in the Site Investigations course, and road construction in the Constructions course.

This shift in focus induces better motivation, as the students experience the applicability of what they learn immediately, and additionally it becomes more obvious to include in the curriculum not only the mathematical/technical skills, but also the professional, personal and social competences as specified in the CDIO syllabus [2].

The composite courses are designed to fully live up to the relevant CDIO standards [3] at the course level:

Standard 1 - The Context: The use of real-world cases put the education in the relevant context right from the start.

Standard 2 - Learning Outcomes: All learning objectives are specified in the course descriptions and given in an operational form with action words [4]. And the formal course descriptions are now being supplemented by additional detailed information on implementation and progression in personal, professional and interpersonal skills.

Standard 6 - Engineering Workspaces: The DTU micro-campus in Greenland is situated right in the relevant engineering workspace for arctic engineering. The arctic conditions are just outside the door, and Sisimiut is a small but self-sufficient town in most ways due to the difficult infrastructural situation in the Arctic. Thus the societal side of engineering is there as well – and we use it intensively in the composite-courses.

Standard 7 - Integrated Learning Experiences: This is exactly what composite-courses are about – integrating all the engineering disciplines necessary to solve a specific case problem.

Standard 8 - Active Learning: The inductive teaching method and active learning environment is based on cognitive constructivism as exemplified by experiential learning methodology with the basic assumption that skills and understanding cannot be given to students – they must be obtained through experience [5].

Standard 11 - Learning Assessment: The learning is assessed as part of the teaching – not as an add-on after the course de facto is finished like the case with a traditional written exam; i.e. both formative and summative assessment is obtained. The learning is assessed on selected work during the semester and the final report – this is in full agreement with the axiom of constructive alignment [6].

DESCRIPTION OF THE COURSE “SITE INVESTIGATIONS”

The course *11821 Site Investigations* is a 12½ ECTS points course of 7½ weeks duration from the beginning of September to the end of October, and is given as the very first course on the Professional Bachelor programme in Arctic Technology.

The overall goal of the course is to teach the students to conduct site investigations in connection with construction work in arctic areas, especially Greenland. It therefore covers technical skills and competences from several different branches of engineering in an interdisciplinary course.

The learning objectives of the course as specified in the official DTU course description are given in Appendix 1. With respect to the CDIO syllabus, we target specifically the following paragraphs of section 2 *Personal and Professional skills and attributes*: 2.1.2 *Modelling* – 2.2.3 *Experimental Inquiry* – 2.3.1 *Thinking Holistically*.

Although the objectives for personal, professional and interpersonal skills are stated rather superficially in only one out of 10 learning objectives, they are not later added appendixes, but integrated into the course objectives from the start. As part of the iterative convergence of the course elements, the learning objectives will be reworked for the next update of the course description with more specific objectives especially for team work.

Course structure, teaching styles and core technical content

In this course, the students acquire an understanding of the relevant geological processes and deposits, as well as tools to examine and map these deposits with a technical focus. They are taught the use of Global Navigation Satellite Systems (GNSS) and Geographical Information Systems (GIS) to collect and organize spatial information in relation to the investigations. The students are also introduced to environmental aspects and cultural heritage screenings.

The course is developed based on an inductive approach, where a case problem (based on a real situation) is introduced in the beginning of the course. Each individual part of the course uses the case problem for application of the methods taught. The idea is that the students develop an understanding of the case problem and techniques to explore/solve it throughout the course, and the main evaluation of the student learning process is the final project report as well as evaluations in the individual parts of the course. The content of this report is developed throughout the course, as the main content and theoretical background is written/prepared during each course element. In the last part of the course, some time is allocated to ensure continuity in the report between the different elements, and develop conclusions, perspectives etc. Figure 1 gives a general overview of the course structure, where topics one by one are treated theoretically, in parallel with work on the case project, field work, analyses and interpretation.

The case is always based on a real-world problem, preferably a real project from the municipality of Sisimiut, e.g. site investigations for the construction of a road in a specified area of town. In this way we impose realistic conditions on the project. All groups work with the same case, but are assigned different parts of the field site for their data collection. In their final reports they will, however, synthesize and discuss the entire collective data set. In this way they are capable of covering a relatively large area and get a realistic picture of the variability in the geological conditions.

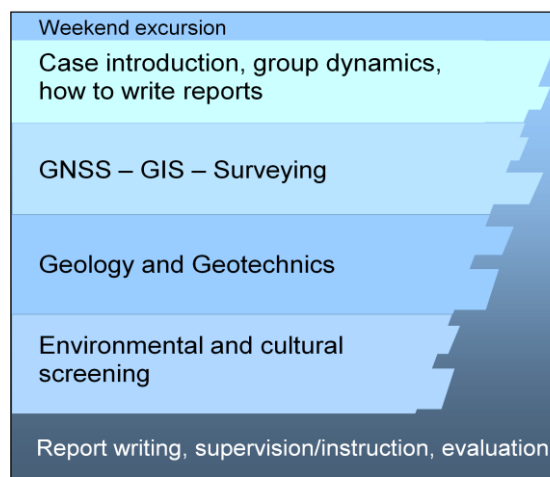


Figure 1: Overall structure of the course. The case problem is used throughout the course as the fundamental scenario, and elements of the final report are produced successively throughout the course.

To give an example of the type of case problem the students are faced with, we present the 2008 project case. The students were asked to produce and report on a site investigation for a new road connection between two parts of Sisimiut. The road was to pass a sedimentary area affected by the presence of permafrost (ice rich soil). Based on the planned placement of the road (information supplied by the municipality), the students were to produce a digital elevation model of the area through GNSS measurements and evaluate surface elevation changes relative to previous models. They were to conduct geological investigations through the drilling of boreholes along the suggested road, and classify obtained samples and measure their mechanical properties. Geophysical measurements were to be collected using geoelectrical and georadar methods in order to provide 2D information about geology and permafrost distribution. They were asked to evaluate the environmental impact of the future road connection as well as to identify any remains of historical interest that might be present in the affected area and which would have to be handled during the construction phase.

Due to this being an early course in their education, and on an introductory level, the students were closely guided in the planning of the field work. However, all measurements, laboratory analysis, data treatment, modelling, interpretation and synthesis were done autonomously by the students under our supervision.

Figure 2 shows an example of the synthesis of an engineering geological model for the area the road is to pass through, produced by students on the course.

After the completion of the student reports, the road project has become a reality, and at the time of writing, the construction of the road embankment is well under way.

Using the inductive form in this way at the course level, and using a real-world problem/case to illustrate the different topics in the course seems to work very well. First of all, it motivates the students, who often comment that it is more interesting working on a realistic project than constructed class exercises. However, it also ensures that the students work with the subject matter at several learning levels (knowledge, application, evaluation, synthesis – with reference to Bloom's taxonomy [8]), depending on the project formulation.

An anchor point of this course is that the students work with real data, and should collect those data themselves. This gives them hands-on experience, and a better understanding (and thus motivation) of what they are doing and why. As in this course we are working with

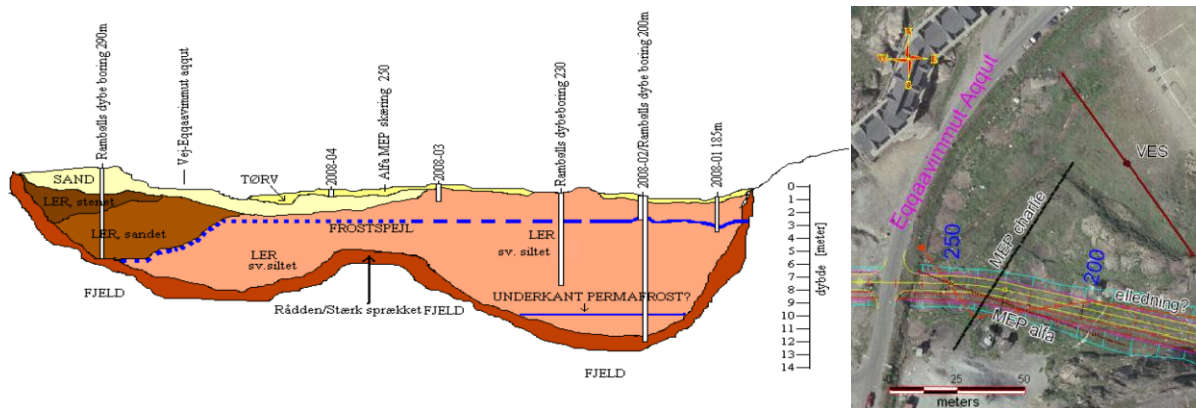


Figure 2. Examples of illustrations from a student report. Left: an illustration of the engineering geological model synthesized from classification of samples from shallow and deep boreholes combined with interpretation of geophysical measurements. Right: outcrop of a map produced to show the projected road trace in combination with the location of geophysical measurement profiles. [7]

very practical geoscience related subjects, nature is our engineering workspace. In order to understand the technical challenges and solutions to foundation and construction problems – the target of a site investigation – the students must first obtain an understanding of the geological materials and the processes that created them. We mediate that by taking them out in nature, to show them the different processes in action. In that respect we are fortunate to have the campus situated in Greenland. We have all the relevant processes – glacial, fluvial and marine – occurring within reach of a short excursion.

Measurement techniques and instrument handling (geophysical measurements, drilling of boreholes, GNSS measurements for creation of a Digital Elevation Model, etc.) is taught in the field, at the case-site, on real world complex geology/topography. Drill cores and samples are brought to the laboratory for further analysis by the students. Supporting lectures are given throughout the course on a just-in-time basis. However, the practical and experimental nature of the course allows for much direct interaction between teachers/instructors and the students and thus is automatically driven by student needs.

Including field work as teaching method is potentially very rewarding for a practical course like this, however it may also pose some dangers and require very meticulous planning. Bottlenecks may easily occur in a suboptimal reality, where multiple equipments are not always available, and different measurement systems operated simultaneously may bias the measurements or render them unusable. Furthermore, working in nature, all parameters are not as easily controllable as when working in the lab, and thus unexpected results are often encountered. If this is not dealt with and explained “real-time” without delay in the field, students feel frustrated, unsuccessful and lose motivation. These are the great risks and challenges when including field work as teaching method. However, when overcome, we find that this is one of the most rewarding teaching styles for this type of subject. Field work should of course always be followed (possibly the next day) by data treatment and interpretation/analysis, and some kind of presentation, either as classroom discussion, oral presentation, or as part of a report to assure sufficient student reflection. This last step is the most difficult and most often neglected in experiential learning [5] – if not sufficient care is put into this, the experience obtained by the practical work will not be transformed into understanding.

One of the main challenges is to get the team of 7-8 teachers from four different departments and an external expert to work as a team. Teachers from DTU are not used to this kind of cooperation. It takes careful planning, a lot of discussions and strict coordination to make the

course a whole - freely flowing from one teacher to the next. But it is possible with engaged teachers, and makes in the end quite a positive difference to both students and teachers.

Personal, professional and interpersonal competences

We find it very important to support the students in their personal development and supply them with the proper tools to successfully complete the main tasks of the case study. In compliance with the CDIO syllabus [2], we therefore focus much time and attention to certain aspects of the professional, social and personal competences described in the syllabus.

The following list comprises such skills and competences which have been selected for special attention in course *11821 Site Investigations*:

- Teamwork and project management [CDIO syllabus 3.1]
- Communication skills and report writing [CDIO syllabus 3.2 (& 3.3)]
- Critical thinking skills [CDIO syllabus 2.4.4]

Teamwork: We wish the students to develop skills of constructive teamwork. This has an extra dimension here, since we form groups to include Danish as well as Greenlandic students, so intercultural problems also have to be addressed. For this reason, a certified coach is part of the teacher team, and helps the students understand group dynamics and write up group contracts, regulating their relations and work ethics.

Project management: Although we guide the students through their project work in this course and follow them closely, we intend them to start familiarizing themselves with the necessity of proper project management in order to produce an acceptable result within a limited time frame.

Communication skills and report writing: Writing a large and complex technical report is very different from the essay-style reports often used in the high school. As this is the first course, we train the students in writing basic technical reports throughout the course, with exercises targeted specifically at report writing skills, as well as individual and group assignments on technical matters to which the students get specific written or oral feedback, also related to the reporting style. Especially some of the Greenlandic students usually have great difficulties communicating in the Danish language, especially when it comes to professional terms. They are therefore offered help from a teacher specially trained in teaching Danish for foreigners to rewrite non-acceptable answers.

Critical thinking: Students coming from the high school need to adjust their mindset to solving real life problems instead of learning facts and methods. This part is addressed by using a real life construction project as basis for their project work. As the problem is not constructed, we don't know the answer in advance and this forces the students to develop critical thinking skills in their work on solving the problem. This is stimulated through continuous discussions and feedback on their work.

STUDENT EVALUATION AND QUALITATIVE FEEDBACK

At the end of all courses at DTU, students are filling in the standard DTU course evaluation questionnaire, which has three sections: A general evaluation of the course, an evaluation of each teacher and a section for additional comments. The students give *11821 Site Investigations* good evaluation as shown for the last year in Appendix 2, but this quantitative evaluation will only be commented very shortly here, since a more elaborate evaluation have been applied as discussed in the next section. The qualitative results from the third section will be discussed later.

The most interesting questions in section 1 are the first 'I think I learn a lot in this course' and the last 'Overall I think this course is good', which on a score from 1 (completely disagree) to 5 (completely agree) in 2010 scored respectively 4.4 and 4.3, which are very good scores. The most difficult question for a large interdisciplinary course is 'I think the teacher makes a good connection between the different teaching activities', which with a score of 3.9 is more than acceptable.

Quantitative evaluations

For two years we have implemented an extended evaluation scheme based on the Course Experience Questionnaire (CEQ) [9]. The questionnaire has been adapted to the DTU course environment by LearningLab DTU: Two of the original categories – *Appropriate assessment* and *Emphasis on independence* – has been replaced by two new categories – *Generic skills* and *Motivation*. In this process the number of questions has also been reduced from 30 to 22, and the questionnaire augmented by an extra question to evaluate the use of Information Technology (IT) in the courses – see Appendix 3.

The modified survey's questions are answered on a scale from 1 to 5, where 5 means "I definitely agree" and 1 is "I definitely disagree". The answers are processed according to the topic of the individual questions and collected in five groups evaluating different elements of the teaching, where a higher score is better. The results for 2008 and 2009 are summarized in **Error! Reference source not found.**, and are all above average. Especially high scores were given on the *Good teaching scale*, the *Motivation scale*, and *IT*.

Table 2
CEQ Evaluation of Course 11821

	Average	2009	2008
Number of questionnaires		14	19
Good teaching scale	3.84	3.94	3.74
Clear goals scale	3.44	3.43	3.44
Appropriate workload scale	3.32	3.55	3.10
Generic skills scale	3.75	3.93	3.57
Motivation scale	3.92	3.97	3.88
IT (The use of IT in the course)	3.99	3.93	4.05

The lowest scoring scale is the *Appropriate workload scale*, indicating that the curriculum for the course maybe was too large, especially in 2008. Due to the time needed for working with the cases and teaching/acquiring new skills such as efficient report writing, less time is available for traditional class teaching. It is quite a complex process to adapt an entire education to a new structure, due to the inter-course dependency of skills and competences. And even after four iterations, there is still room for improvement.

Qualitative evaluation and feedback

The third section of the DTU standard evaluation has room for both positive and negative feedback and suggestions for improvements. Furthermore an oral evaluation session has been conducted every year by the head of the study program, without attendance of the course teachers to allow the students to speak more freely of any problems and concerns.

Both written and oral feedback about the course is in general very positive. Phrases such as “Exciting and challenging” and “I learned a lot” are typical throughout the evaluations.

The practical focus is mentioned as a motivating factor. Both in terms of the overall case, to which each course element is attached:

“Good coherence in course – logical progression”, [oral feedback, 2010]

“Good balance between practice and theory”, [DTU course evaluation, 2010]

and with specific reference to practical exercises and excursions in the field and the main fieldwork collecting data for the site investigation report:

“It was good that we conducted fieldwork, it made it more interesting”, [DTU course evaluation, 2009]

“Nice with exemplification through field excursion”, [written feedback, 2008]

Although the course comprises six elements taught by different teachers from four different engineering departments (one is external lecturer), it is our intention that the course should be coherent and appear as one continuous progression to the students. The feedback from the students indicate that we have come quite far in this regard, but there are still weak points in tying some of the elements properly together. Unfortunately, these points are very apparent to the students, who also reflect on them in their feedback:

“The course structure is good, but I miss a little more coherence between the geodesy and geology elements”, [DTU course evaluation, 2010]

“It felt like the teachers had not discussed the purpose of some of the exercises, and some things were repeated in connection with GPS/GIS”, [DTU course evaluation, 2010]

This is certainly a point to improve on in the future.

In the oral feedback session of 2010, one student commented that the teacher in each element ought to do more to “try to prepare for the next theme”. We find that this is an excellent observation. Although the course responsible has been the recurring face throughout the course, starting the course, teaching a central part approximately half way through, and rounding off the course, it is not possible to have him/her available at all transitions during the course. There has probably been a tendency for the individual teachers to focus more on their individual elements – following the coordinated strategy the team has prepared together for that particular case – and not so much specific focus on tying that element on to what came before and what will come after.

From time to time we also observe critique of deliberate choices made in the course planning. Often this critique is caused by the different teaching style the students have been used to during secondary and high school:

“At times, too many things were going on at the same time, which meant that each student used much time on some parts, but did not become acquainted with the other experiments”, [DTU course evaluation, 2010]

Since we are treating a real world complex case, many things need investigation. We have tried not to sacrifice the complexity of the real case for simplicity in teaching and coordination in class. The course has thus been structured such that in each group they will have to distribute tasks among the group members, working in pairs or individually on some parts and then report the findings back to the group. It is actually one of the learning objectives of

the course to introduce them to efficient team work in an engineering setting. This is the reason for having a certified coach in the teacher team. The involvement of the coach is seen by the students as good support:

“Good thing with the coach – although too short”, [oral feedback, 2008]

Acquiring such skills early is of course of great importance, as many of the courses they will encounter throughout the education is based on group work, and not least because once educated engineers, the students will have to engage in interdisciplinary cooperation with people of many different professions.

TEACHER’S EXPERIENCES

One of the experienced teachers involved in the education from the very beginning, has been teaching geodesy and GNSS both before and after the restructuring of the courses. He pinpoints the very difficult problem of restructuring a well established curriculum in engineering education:

“However, the composite courses introduced a serious pedagogical problem ... because the elements needed for site investigations, which with the new structure of the education were to be taught in the very beginning of the education, were the most theoretical and calculation-heavy within our profession”, [Keld Dueholm, personal comm., 2011]

With the same overall time frame for the education, and more focus on the professional and personal skills, there has been an ongoing discussion about the influence on student learning:

“Since the time available for the technical content was significantly reduced in connection with the composite courses, I never reached the same technical depth and engagement with the students as previously”, [Keld Dueholm, personal comm., 2011]

This is backed by Lars Stenseng, who has been teaching the geodesy and GNSS element for the past 2 years following Mr. Dueholms retirement. He explains that due to the focus on process, there is less time for the traditional teaching of core theoretical basis, compared with similar courses at DTU [Lars Stenseng, personal comm., 2011].

He concludes that although his students in Denmark obtain a deeper theoretical understanding, it is still not sufficient to be operational for e.g. research or development purposes. On the other hand they lack the practical knowledge and experience that the students obtain in the composite courses, through the interdisciplinary application in the case project work.

“I think this way of teaching better fits a professional bachelor engineering education”, [Lars Stenseng, personal comm., 2011]

Especially this positive effect on the learning process through the link of different disciplines is noticed by many teachers in the team:

“I see the composite courses as a good tool to create a link between the subjects under the teaching conditions present in Sisimiut”, [Keld Dueholm, personal comm., 2011]

“The fundamental case in the course gives a better more natural flow and progression in the learning process”, [Lars Stenseng, personal comm., 2011]

The results are quite evident to another teacher, who has been teaching the engineering geology and geotechnics element from the start of the education, at which the location of all samples and geophysical measurements were measured with measurement tape relative to recognizable points in the terrain, in order to produce crude maps for the reports:

“The reports we have received from the students in the last few years are much better than previously. The students show deeper comprehension of the technical content, and their writing and data presentation has also improved. This is a direct effect of linking the geotechnical and the GNSS and GIS elements in one course”, [Niels Foged, personal comm., 2011]

However, he thinks that the cultural heritage and environmental elements are not in their full context coordinated with the above topics and may complicate the students understanding of societal relations to the factual investigation results.

The course structure and especially the basic case project also improve the students' ability and willingness to take charge of their own work:

“With the new course structure, the students have become better at taking initiative of their own field measurements – based on a predefined plan”, [Niels Foged, personal comm., 2011]

We speculate that this is due to the understanding of the overall context of the measurements they are to perform. This is a general observation not only linked to the field and laboratory work, as the teacher in the GIS element explains:

“The case project makes the students more mature in their approach. I see them more motivated - They just want to learn!” [Darka Mioc, personal comm., 2011]

The ones who are there, she goes on to add, because there are problems with students not showing up for classes. Such problems, however, are even bigger in Denmark, she concludes. This difference is probably due to the practical and real world case used in Greenland:

“The way we teach in Greenland is much more motivating than how the same topics are taught in Denmark. It is being used in the end – the road actually gets built!” [Darka Mioc, personal comm., 2011]

“Even those who don't really care for a specific element, become motivated to learn through the further application in other course elements”, [Lars Stenseng, personal comm., 2011]

One challenge with intensive, full time, courses is that there is no time for self reflection, and thus it is more difficult to obtain the intuitive understanding of the technical content. This is typically observed in the short intensive three-weeks courses that are part of the DTU Denmark semester plan, but a real-world approach could help the student to think out of the box:

“It is my impression that the more practical approach based on a real-life case helps the students obtain the understanding in spite of the time pressure.” [Lars Stenseng, personal comm., 2011]

Although the technical content is not directly comparable to what Darca Mioc teaches in Denmark, it is evident from her comments that she is happy with the course and the student outcome:

“The course is really very good! ... I feel comfortable teaching in this way ... I think they learn much more in Greenland”, [Darka Mioc, personal comm., 2011]

CONCLUSIONS

During restructuring of the Professional Bachelor programme in Arctic Technology in Greenland, the CDIO concept was incorporated in the course structure, and educational elements of individual courses were reorganized to form interdisciplinary courses on specific engineering relevant topics.

The interdisciplinary structure of the course *11821 Site Investigations* combined with the real-world case and just-in-time teaching applied has resulted in more motivated and hard working students. They attend classes and practical sessions, and they put much energy in the writing of their final projects. It has also introduced personal, professional and interpersonal competences in a natural way. As teachers we receive far better and more interesting reports to read, due to the fact that several tools are combined to provide a better understanding of a certain problem.

The transition from traditional theoretical and topical courses to interdisciplinary and practically oriented courses pose special demands on teachers and instructors/tutors, among these are more complex (and very important) coordination among different course elements as well as adaption of the curriculum.

We have presented student evaluation data available from a CEQ-like test as well as qualitative statements from the standard DTU course evaluations and individual student feedback to support our findings and conclusions. The feedback confirms that the new composite course form is an efficient and challenging way to teach engineering with good learning outcome over the broad spectrum of the CDIO syllabus.

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APPENDIX 1

Learning objectives for course 11821 Site Investigations:

A student who has met the objectives of the course will be able to:

- Plan, carry out, process and evaluate GPS-measurements in connection with site investigations.
- Work with datum, map projections and control points in Greenland, and be able to transform coordinates between the systems.
- Use GIS to collect data from field measurements, maps and orthophotos and to organize presentation of data.
- Describe relevant geological processes and deposits and develop engineering geological models as a framework for site investigations.
- Complete engineering geological classification of soils and rocks, as well as measure and describe the strength characteristics.
- Conduct simple geophysical investigations and apply the results in relation to geology, geotechnics and permafrost.
- Conduct a simple environmental investigation in an arctic area.
- Recognize signs of prehistoric remains.
- Describe forms of cooperation, draw up a group contract and write a basic technical report that complies with formal demands.

APPENDIX 2

Results from official DTU course evaluation 2010 (section 1, scale from 1 to 5):

22 students have answered the evaluation form (out of 22 attending the course)

1.1	I think I am learning a lot on this course	4.4
1.2	I think the teaching method encourages my active participation	4.2
1.3	I think the teaching material is good	4.1
1.4	I think that throughout the course, the teacher/s have clearly communicated to me where I stand academically	3.8
1.5	I think the teacher/s create/s good continuity between the different teaching activities	3.9
1.6	5 points is equivalent to 9 hrs./week (45 hrs./week in the three-week period). I think my performance during the course is (5 more – 1 less)	3.6
1.7	I think the course description's prerequisites are (5 too low – 1 too high) [There are no prerequisites]	2.9
1.8	In general, I think this is a good course	4.3

APPENDIX 3

Questions asked in the modified Course Experience Questionnaire, and abbreviation of the appropriate scale to which the result is assigned:

1.	This course was intellectually stimulating	MS
2.	The aims and learning objectives of this course were NOT made clear	*CTS
3.	The teacher normally gave me helpful feedback on my progress	GTS
4.	It seems to me that the syllabus in this course tried to cover too many topics	*AWS
5.	The teacher showed no real interest in what the students had to say in this course	*GTS
6.	I have usually had a clear idea of where I was going and what was expected of me in this course	CTS
7.	I have found the course motivating	MS
8.	It was often hard to discover, what was expected of me in this course	*CTS
9.	This course helped me sharpen my analytical skills	GSS
10.	This course made me feel more confident about tackling new and unfamiliar problems	GSS
11.	This course has stimulated my enthusiasm for further learning	MS
12.	In this course it was always easy to know the standard of work expected from me	CTS
13.	The course helped me to develop the ability to plan my own work	GSS
14.	Where it was used, Information Technology has helped me to learn	ITS
15.	I was generally given enough time to understand the things I had to learn in this course	AWS
16.	The teacher made a real effort to understand any problems and difficulties I had in this course	GTS
17.	This course has stimulated my interest in the field of study	MS
18.	This course developed my problem-solving skills	GSS
19.	The teacher has put a lot of time into comments (orally and/or in writing) on my work	GTS
20.	In this course it was made clear right from the start what was expected from me	CTS
21.	The teacher worked hard to make the subject of this course interesting	GTS
22.	The volume of work necessary to complete this course means that it cannot all be thoroughly comprehended	*AWS

Abbreviations:

GTS	Good Teaching Scale
CGS	Clear Goals Scale
AWS	Appropriate Workload Scale
GSS	Generic Skills Scale
MS	Motivation Scale
ITS	Good use of IT scale
*	Indicates that the result is reversed before it is added to the appropriate scale.

“Good Teaching Practice” at DTU Systems Biology - Sustaining quality in teaching and learning

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ABSTRACT

Success in developing teaching and learning in engineering education in general, as well as in a CDIO context, depends on continuous development of teaching competences among faculty members. Thus, it is essential to develop systems that promote understanding of how teaching and assessment can support student learning within disciplinary knowledge as well as development of professional skills. Development and maintenance of high quality teaching and learning furthermore requires that teachers have the ability to reflect critically on their teaching activities and understand its impact on the students' learning process. To succeed in reaching these goals, development of teaching competences and knowledge in the fields of teaching and learning must be combined with continuous possibilities to reflect on teaching practise in a structured way. Development of successful teaching also requires that faculty members are inspired and encouraged to try new ways and methods in teaching, and gaining an extended understanding in how students learning can be efficiently supported.

In this paper we describe a novel initiative, a concept of Good Teaching Practice, that has been developed through a process involving faculty at the department of Systems Biology at the Technical University of Denmark. The GTP initiative addresses important factors for effective teaching and enhancement of student learning. On the surface GTP is structured as an online tool, which makes six statements about important factors that support student learning that the teachers at the department are supposed to consider. This is coupled to a wiki-based web resource for sharing good examples from teaching practice among faculty. By formulating a teaching and learning profile at the department level the importance of teaching for the department are emphasized and at the same time, the wiki-based resource for sharing teaching experience shows that teaching is a shared responsibility among the entire faculty. On the website, the theoretical framework underlying GTP provides a shorthand introduction to the important prerequisites for students learning and provides definitions that provide the faculty members with a common language to use in discussions of teaching and learning. The GTP concept addresses standard 10 in the CDIO context which focuses on the enhancement of the development of teaching and learning at department level and provides the teachers with tools to conduct teaching proficiently.

KEYWORDS

Teaching and learning development, teaching competences, enhancement of quality in engineering education

INTRODUCTION

At the Technical University of Denmark several activities has been initiated at the university level in order to support the teaching and learning development at the university. LearningLab DTU, the central unit for development of teaching and learning, run a compulsory teacher training program for all new faculty. They also give seminars and short courses on teaching matters and are involved in the development of e-learning tools and participate extensively in evaluation of courses and educations. Those activities provide DTU with a good frame to 1) develop teaching methods to enhance learning, 2) to enhance the understanding among DTU faculty of the prerequisites of student learning and 3) develop teaching competences at the university.

Even if all the necessary prerequisites for faculty members to develop their teaching competencies and to understand the important factors in student learning are available at a university, it is still a challenge to secure conversion of the theoretical knowledge into teaching practice. High quality in teaching requires that this transmission is actually taking place to support student learning efficiently, to motivate the students in their performance and to support retention. This has been one of the main challenges in Higher Education in the past decades [1].

The most important objective during teacher training is to ensure the creation of a loop of quality enhancement where teachers implement adequate teaching methods for support of the intended learning outcomes, and assesses the students in accordance with these [2]. Constantly the teachers should take student evaluation into account and conduct self evaluation in order to develop their courses and teaching.

A development like the introduction of the GTP concept depends on many factors at the organisational level and its development depends on support from administrative structures and incitements [3]. The importance of teaching and learning to the department may be communicated to the faculty, and the organisational culture may or may not be supportive to new initiatives in teaching and assessment methods. In the supportive environment initiatives may be encouraged and praised, while alternatively in the non-supportive environment the same initiatives may be regarded as waste of time. The view on course evaluations is interconnected with this attitude. Evaluations may be seen as a tool for improvements or alternatively as a necessary control mechanism. The latter view could result in the conservation of the teachers' approaches to teaching and learning as it becomes important to act on safe ground instead of try out new methods. A solid base for quality enhancement of student learning can only arise in a working environment where teaching and learning are openly discussed and regarded as important aspects of the faculty profession, and in which the teacher should continue to improve their abilities to create a successful learning environment. This fruitful dialogue among faculty members about teaching and learning within special disciplinary subjects is one of the most important prerequisite for ensuring and sustaining quality in engineering educations [4].

These prerequisites are addressed in the CDIO-initiative in Standard number 10, "Enhancement of Faculty Teaching Competence". Standard 10 stresses that "if faculty members are expected to teach in new ways, as described in Standards 7, 8 and 11, they need opportunities to develop and improve these competencies" [5]. Examples of actions that enhance faculty competence such as "support for faculty participation in university and external faculty development programs, forums for sharing ideas and best practices, and emphasis in performance reviews and hiring on effective teaching methods" are described [5].

Department of Systems Biology at DTU consider teaching as one of the most important activities, and has a long tradition of encouraging developments in this field. To further improve the student learning environment a decision was made to invite the entire faculty to take part in the development of the departments teaching and learning. One of the initiatives was to meet a number of issues commonly addressed in the course evaluations. This development was primarily aimed at taking the step from teachers simply attending courses and taking teacher training programs to create a culture at the department where the knowledge each teacher possesses could be used for a general and common development of the teaching and learning at the department.

An essential part of the project was to provide the faculty members with a tool to encourage deep learning among the students and the knowledge to create a good learning environment in the courses and educations at the department. The project was also aimed at creating possibilities for a dialogue among faculty where teaching and learning was the subject. Development of a community of practice and the sharing of good teaching practice in order to fulfil those aims has previously been described by Wenger (E Wenger). The result of the current project is the concept of "Good Teaching Practice", abbreviated as GTP. GTP is a web based tool with six standards that was found to be important for faculty members in their teaching practice. The web based GTP also contains short explanations of why those standards are important, and a wiki-based resource where teachers can upload and share examples from their teaching practice.

This paper describes the development of the GTP concept and the implications and ideas behind it. Some experiences from the short time after its implementation will also be addressed.

The problem addressed is how to ensure and sustain quality in teaching and learning in an engineering education with focus on student learning, coupled to motivation and development of faculty skills in this area. Many of the activities during the development of the GTP concept are found in CDIO Standard 10. This paper will examine some of these activities in relation to the process in developing the GTP concept and their benefits to the department of Systems Biology at DTU.

PREREQUISITES FOR A SUSTAINABLE TEACHING AND LEARNING DEVELOPMENT

In CDIO standard 10 enhancement of faculty teaching competence are dependent on the following prerequisites

- Majority of faculty with competence in teaching, learning, and assessment methods, demonstrated, for example, by observation and self-report.
- University's acceptance of effective teaching in its faculty evaluation and hiring policies and practices
- Commitment of resources for faculty development in these skills [5]

Those statements clearly indicate that teaching and learning development need to be framed at the organisation level but also need to be supported by a general acceptance that quality in teaching is prioritized high enough to motivate a busy university teacher to improve in this field.

Motivation is the key factor if any busy professionals should chose to use time on changing the way they act and think. Naturally, this is also one of the central prerequisites for involving university teachers in developing teaching and learning [6]. In teaching and learning development at universities there are special factors, based upon the university context which has an impact on the motivation of faculty members. The priorities of a faculty member at a university need to be balanced between many tasks. Boyer analyzed the role of university faculties and pointed out that a number of tasks are important in the post modern society, for the education of highly qualified professionals. Different tasks are needed to produce knowledge and research of high standards, to contribute to innovations and to ensure that this knowledge is used and spread, and all tasks have to be performed in a scholarly way [7]. Many complex tasks are thus required of the universities and their faculty, and here engineering educations receive special attention from society because engineers and engineering knowledge is considered to play a central role in meeting new challenges today and in the future. In many reports evaluating engineering educations, e.g., Sheppard et. al [8], these issues are addressed. The special awareness and attention required from teachers in engineering educations is addressed in the CDIO initiative [5]. In the first phases of the faculty-driven GTP project at DTU Systems Biology both motivation and prioritizing of high quality teaching among other duties at the department level were recognized as extremely important. Ownership of the GTP context and the acknowledgment of prior experiences as valuable were found to be motivating factors for commitment to the development of the concept. Difficulties in implementing new ideas and activities in an organisation may be reduced if the development process is taking place within the organization and is performed by the persons that are influenced by the changes [9]. Faculty involvement in a bottom-up process was one of the bearing ideas in the development of the GTP concept, and benefitted from the large body of experiences and knowledge about teaching and student learning among the staff at the department. When messages were communicated from the department administration these emphasized the importance of creating a good learning environment for the students at the department. The learning-focused approach was a highly motivating factor in the development of GTP.

In the overview by Southwell and Morgan concerning the impact of research activity on academic staff development and leadership, the authors come to the conclusion that the contextual elements in which university teachers work and teach have shown to be one of the most important factors in the creation and sustain of teaching and learning development [10]. These ideas were taken into consideration during the GTP process to create a community of practice [11]. One prerequisite to creating a community of practice within teaching is to provide the teachers with adequate knowledge about student learning and about how this can be supported during teaching. During the GTP process the participants set out to present this knowledge in a very simple format of one-liners, trying to capture the interest of the audience.

EXISTING INITIATIVES AT THE DEPARTMENT SERVING AS A PLATFORM FOR THE GTP PROCESS

DTU Systems Biology already housed a variety of structures and activities to support teaching and learning development, when the decision was made to develop the GTP concept. These structures are described below.

Infrastructure for teaching and learning development at DTU Systems Biology

DTU Systems Biology has a long tradition for a high priority of teaching and development of teaching competencies. This view has been clearly communicated from the head of the department, as well as from the management level. As other departments at DTU a director of studies has been appointed, who also is the head of the study board. The study board comprises an equal number of students and faculty members. The board takes initiative to different projects in teaching and learning, point out relevant and important questions in this area, go through course evaluations and arrange seminars about teaching and learning regularly at the department. Some of faculty members in the study board have been appointed study leaders for the various educations hosted by the department. In view of the importance of these tasks, study leaders have been appointed for each separate education, i.e., two bachelor study leaders and two master study leaders.

Another part of the educational infrastructure are a number of pedagogical peer coaches, serving as educational supervisors that coaches new staff members towards efficient and high quality teaching at DTU. This peer-coaching serves as a part of the compulsory teacher training programme. Because of the teacher training programme, younger faculty members share a common educational background in teaching and therefore share the same language and ideas about teaching and learning, including the role of teaching at universities. A common language is central for sharing teaching experiences with each other, and to participate in discussions about teaching and student learning on an overall level. The teacher-training program includes a project based upon actual teaching practice of the students.

The department hosts a number of docents, i.e., professors appointed with special tasks in development of teaching and learning which met regularly with the study leaders and the institute head, for discussions on future educational initiatives and developments in the different programs.

To ensure a continuous discussion on teaching and learning among faculty-members, as well as to stimulate the staff to try new methods the director of studies is semi-annually organizing teaching and educational seminars, where different aspects of high quality teaching and assessments.

Together the infrastructure at DTU Systems Biology provided a platform for discussions, debates and dialogue about teaching and learning at the department that enhanced the development of the GTP concept.

Student dissatisfaction leads to initiation of the GTP process

While the department had created a culture where teaching and learning could be discussed and developed in dedicated circles, there were still evident problems in ongoing teaching activities and courses. Student evaluations of certain courses showed recurring problems and students were often complaining to the department head, when they were asked about their satisfaction. To meet those challenges the department head offered the management the task of formulating a set of statements that emphasized the most important elements in good teaching for creation and sustain of the prerequisites for efficient student learning. Those statements should also increase the understanding of good learning in courses and education programmes. For the department educational infrastructure those statements should also point out the requirements that every teacher in the departments was supposed to live up to. All the points should be in accordance with current knowledge about optimal

teaching practice. Professional support in formulating the statements was obtained from LearningLab DTU, the central teaching and learning-developing unit at DTU.

THE GTP PROJECT ON GOOD TEACHING PRACTICE

At the onset of the GTP project, the department tried to take into account the important factors in organisational developing processes that aim at creating sustainable changes, as mentioned previously in this paper. Therefore a more extensive process was implemented to define a set of statements describing good teaching practise, and ensuring that they agreed with the current research in the field of teaching and learning in higher education. Representatives from faculty at the department were invited to join the process, in order to root the concept in the department, and to ensure the relevance of the results for the teachers. A project steering group was formed consisting of the director of studies at the department, representatives from faculty, an educational consultant, and representatives from the department management and administration. The resulting project was launched under the name “Good Teaching Practice” concept, or GTP for short.

Student involvement and focus on student learning

The students following the education programmes at the department of DTU Systems Biology played a central role in the development of the GTP concept. Thus, in the initial phase of the process, students at different stages in their educations, were invited to define what they considered to be recurring problems, and to include their experience in how an optimal learning environment is achieved in different types of courses.

Resulting from this meeting were different student statements that could be structured logically into areas that required further improvements to strengthen the students’ learning. Among the important insights were that the students lacked a sense of coherence and progression in the education programmes, they experienced little variation in teaching methods and a lack of continues feedback. With a departure in this feedback, the educational consultant could list a number of means to solve these problems, based upon the theory of student learning in higher education.

The meeting with the students also prompted the assigning the year 2010 to be the year of teaching at the department, where teaching and learning should be in focus. The meeting also resulted in the launch of a teaching debate forum in the form of a blog, where students could write about their experiences from the courses at the department.

Working process involving faculty

To facilitate a sustainable development in teaching and learning it was decided to involve faculty as much as possible in formulating and structuring the statements on good teaching. As mentioned, the strategy was to root the concept in the faculty that should end up using it, so that already existing knowledge and experiences at the department would come into use, as well as to ensure that the end-product would be relevant for the teachers. Therefore the process started with meetings among faculty members to share experiences that each felt could improve teaching. Thereby the concept was implemented directly from the beginning and a sense of ownership for the concept could be created at the department.

It was concluded that it was important to depart from the conclusions from the student meetings to and implement the theoretical knowledge about teaching and learning in higher education in order to develop an evidence based theoretical frame in the concept.

The faculty groups were formed with representatives from faculty around the structured themes. All faculty members were invited, and almost half of all members took part in the process. Groups discussed the meaning of each student derived theme and its implications for teaching and learning at the department. The teachers also shared examples from their own teaching practices and considerations about what they thought were of importance for good teaching practice. The results from the group discussions were structured and edited by the educational consultant in cooperation with the rest of the project group, and further discussed in the working groups in an iterative process.

Along the faculty group meetings there were regular seminars about teaching and learning at the department addressing the work on GTP in order to involve as many faculty members in the process.

The final result was edited by the project group and launched as a web-based tool.

GTP, GOOD TEACHING PRACTICE, - THE CONCEPT

On the surface, GTP is a web-based tool consisting of three levels. Six statements are formulated as “punch lines” about important factors that support student learning in higher education. The six statements concern the planning and conducting teaching with emphasis on student learning, and how to evaluate student learning and teaching in courses:

- Identify the level of your students
- Teach the important aspects
- Encourage deep learning
- Ensure coherence
- Ask students for advice on teaching
- Learn from your colleagues

Among the six central statements that define the GTP core, the last one addresses the fact that faculty need to continually develop their teaching competences and contribute to the discussions about teaching and learning at the department.

Each statement is followed on each new web page by explanations of why that particular statement is important in relation to teaching and learning in higher education. The theoretical frame in GTP rests on the phenomenographic focus on the importance of deep approaches to learning among the students [12] as well as the models of Constructive Alignment and intended learning outcome in course planning [2].

The third part of the GTP concept consists of a toolbox in wiki-format where relevant material and examples from teaching practices at the department are compiled and described. From this toolbox, faculty can get ideas and inspiration from each other on how to apply the six statements in practice. The main purpose of the toolbox is to provide a forum for faculty members where they can be inspired and share experiences from their teaching practice at the department. Materials of relevance from other universities are also available in the toolbox.

The role of the GTP concept is twofold. Its primary role is a supporting tool for the teachers when planning and conducting teaching, but it also serves as a teaching and learning profile at the department.

EXPERIENCES FROM THE DEVELOPMENT OF THE GTP CONCEPT

In order to follow up how the objectives in the GTP project have been met, and to get knowledge about how GTP concept, an initial evaluation has been made. At the time of the evaluation the GTP concept, the web-page had been available at the department for about six months.

Focus groups interviews with 11 out of 55 faculty members were held. The 11 participants were divided in two groups. The topics for the interviews were, how they perceived the GTP concept and how they used it, and if they had done so - under which circumstances.

Some of statements were made by faculty members following both groups. The conclusions from these statements are listed below.

- The process of creating the GTP was very good and useful since it has catalyzed an habit of discussions with colleagues about teaching and student learning at the department.
- Faculty members do not use GTP on every day base.
- If a teacher run into problems about teaching in courses this will be the time to turn to the GTP concept in order to get things right.
- When courses have to be changed or new ones invented, GTP may be very useful.
- Faculty members have gained a greater awareness about the coherence in the education programmes at the department, as well as the importance of considering the position of each course in this coherence.
- Faculty members have learned to know their colleagues better.
- Faculty members have gained insight in how many different methods can be used in teaching and assessment, and that not every teacher does the same. Their conclusion is that they can learn from other teachers and are more interested in trying new methods.
- It is useful to gain knowledge about different examples from teaching and learn from the experiences of other teachers and that they are easy to get access to in the wiki, because they have so little time to find out about new teaching methods in their every day work.
- Faculty members think that GTP will be to a great help for new teachers at the department.
- It is very useful and good that teaching, through the GTP process, has been recognised as one of the main activities at the department and that is now is acknowledged that time and resources also can be spent on teaching an course development.

CONCLUSIONS

So far we may conclude from the GTP project on developing a Good Teaching Practice concept at the department level, that a sustainable development of teaching and learning can

be successfully initiated by fulfilling theoretical requirement stated in the CDIO standard 10 and evidence based studies about learning and development in organisations.

Bringing academic staff together to discuss teaching and learning and by bringing these discussions in the official context of the departments running activities has shown to have a strong impact on creating a consciousness that teaching and learning is a prioritised field. There are some indications from the interviews that many faculty members actually think that research must be the area of highest priority because the importance of teaching is not always explicitly communicated and discussed, neither is the incentive for delivering high quality teaching as evident as the incentives for performing world-class research. The reason for this could be that teaching traditionally is regarded as a private matter resting on traditions that do not need to be openly discussed. An open and structured discussion supported from the management level, signals the importance of continuously developing teaching practices.

Another result of cross-faculty discussions seems to be the recognition that good teaching can be developed and trained instead of being regarded as a gift some teachers are naturally given.

Teaching and learning in higher education is a research field with scholarly knowledge. This is extremely important when trying to enhance the quality in teaching and learning. If this knowledge is used in the everyday teaching practice, this may be the crucial factor for recruitment of students to engineering educations and for providing them with an efficient and motivating learning environment. Early indications suggest that a process like the GTP at DTU Systems Biology, where teachers are actively involved formulating standards for good teaching, can contribute to this. A clear communication and support from management level and staff allocated to take the responsibility for teaching and learning development at the department are important to ensure a sustainable development in this area.

To create a sustainable teaching and learning development there must be clear objectives and a clear frame that sets some standards and contribute to create an understanding among teachers why the criteria are important to fulfil in their teaching practice. To succeed, there must be support systems to provide faculty with structured knowledge about teaching and learning in higher education in addition with a cultural context at the department where teaching is acknowledged as an activity of high priority.

Most important is the creation of a motivating and inspiring learning environment for faculty about teaching and student learning. Inspired teachers with a curiosity to explore teaching and its impact on students learning is the best guarantee for a sustainable teaching and learning development. It is also a guarantee for the motivation of student to obtain high quality learning in courses and educations. Future experiences from the GTP concept and the process started at DTU Systems Biology to create a sustainable teaching and learning development at department level will hopefully bring more knowledge how CDIO standard 10 can be ensured in engineering education.

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Biographical Information

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Mogens Kilstrup holds a PhD in molecular biology at the University of Copenhagen and was employed as assistant professor at the Technical University of Denmark in 1994. He has worked as Associated Professor at Department of Systems Biology at DTU from 2000 to 2008 where he was appointed professor with special responsibilities within teaching. From

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Pernille Andersson is educational consultant at LearningLab DTU at the Technical University of Denmark. She is coordinator and responsible for the compulsory teacher training program at DTU as well as other competency developing activities in teaching and learning. Pernille works with projects aimed at developing teaching and learning at DTU departments, and at DTU in general. She also works with deeper evaluation of new teaching methods and teaching and learning initiatives at DTU. On national level, Pernille is a representative in the steering committee of DACIN, a network supporting educational development in engineering education at the technical universities and university colleges in Denmark.

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LEARNING DIGITAL DESIGN THROUGH ROLE PLAYING

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ABSTRACT

This article presents an experience carried out by the Digital Systems area in the Electronic Engineering program, using problem-based learning (PBL) and mobile technologies. This assessment makes use of both the concept of learning and the professional profile of electronic engineers proposed by the MIMESIS Research Group and CDIO Initiative, in order to present project-based learning as the didactic strategy underlying this experience. Results are presented based on two dimensions: first, the interactive dimension, which encompasses the flow and the kind of communications established between the students along the process, enhancing their interpersonal abilities. Second, the pedagogical dimension, which makes it possible to assess the experience bearing in mind three criteria: motivation, learning and collaborative work. Additionally, a number of factors which can explain the results are identified.

KEYWORDS

Problem based learning, teaching in engineering, electronic engineering.

INTRODUCTION

Advances in both technology and complex digital systems demand design-related competences on the part of electronic engineering professionals. The development of such competences must be encouraged since the earliest stages of their professional training. In order to respond to these challenges, the Digital-Design academic subjects in the Electronic Engineering Program at Pontificia Universidad Javeriana were modified in both their methodology and contents. The digital design subject, which is part of the program's training core, is to be taken during the seventh semester in a five years program. In terms of methodology, the style of classes changed from lectures to project-based sessions, where collaborative work, knowledge development and professional-competence acquisition are stimulated [6].

In order to promote the development of basic professional competences, a number of professional life experiences focused on the electronic solutions industry were integrated into class sessions. This was done bearing in mind that products in this area are developed by task groups with specific functions, and that the complexity of designs demands collaborative work among engineers who are significantly distant from each other; it demands efficient communicative processes which enable different groups to reach high-quality outcomes. This led to the development of "role-plays," a didactic strategy which is useful for an appropriate development of electronic engineering tasks.

The project-based learning component covered the CDIO cycle: conceive design, implement and operate a digital system [1] [2]. It was developed by teachers at the Electronic Engineering Department at Pontificia Universidad Javeriana, Bogotá (Colombia), together with the MIMESIS Research Group which coordinates the CDIO reflexion.

ROLE-PLAY DESCRIPTION

The role-play designed simulates real-life conditions in the development of digital systems, as a real CDIO experience, where interaction between designers and architects takes place in the distance, and where each participant has independent tasks to carry out [4][5]. Two roles were defined in this activity: architects and designers. Distance between these groups of professionals was simulated by involving two class groups, each with different teachers and class-schedules: groups A and B. Two or more projects are proposed so that architects are part of group A and designers are part of group B. Roles are shifted in the second project so that everyone can be both an architect and an engineer. Participants must change counterparts too in order to expand the range of communicative interaction.

The game is scheduled to take place during the last five weeks of each semester. First, the systems to be designed are proposed as if they had been requested by a client. All the groups take the role of architects and produce system specifications, the blocks diagram, and the timing description of the system. This stage lasts two weeks and a half, and is carried out in and out of the classroom.

Once the architecture stage is over, each group sends documents to their designers via the Blackboard® platform. Then all groups become designers, and their first task is to review the document describing the architecture of the system. Doubts and questions arising from this preliminary review are addressed to architects, who then make corrections and provide further information in order to continue with the development of the project.

Designers describe the system hardware using AHPL language [3], and then develop a diagram based on the specifications provided; after that, they describe the system using VHDL language, and finally it is both simulated and implemented using the programmable logic device. A record of the interactions between groups is kept in order to follow up the learning process, the quality of their work, the most common doubts and the answers provided by each group. This is all documented in order to gain a comprehensive picture of the activity.

In order to follow up and classify the interactions that take place between architects and designers, an online discussion forum was created. Additionally, a taxonomy comprising all the possible forms of interaction was created in order to classify the actions taken by groups in the forum. This record makes it possible to identify changes in interaction along the experience.

INTERACTION TAXONOMY

During the first semester 2009, the records of an experience carried out showed a total of 121 interactions between the 18 groups involved. First, such interactions were analyzed by the research group. Then, they were classified based on the communicative objective designers had in mind. Once this taxonomy was established, it was used to identify forms of interaction in forums. This information was the basis for the study of developments in a number of communicative abilities, and for the analysis of learning achievements.

Interaction by students was classified into categories based on the kinds of requests they made. Each interaction category was defined as follows:

Information requests: when data are needed.

Argument requests: when the criteria followed by designers and architects differ concerning proposals by the latter.

Clarification requests: when a designer is not clear about the proposal given by an architect.

Proposal requests: when designers present architectural solutions or modifications once they find a possible error.

Replies by architects were classified bearing in mind emerging categories based on analysis by researchers. The following categories were identified:

Information replies: they limit themselves to data transmission.

Correction-based Information replies: they are correction-gearred procedures that are based on the absence of information in a given specification due to a conceptual error by architects.

Informative replies that generate self-correction: they happen when information requests by designers cause architects to detect errors which had not been identified before.

Clarifying replies: they explain design choices based on criteria and concepts learned in class.

Argument replies: they generate debate.

Teacher-mediated replies: they take place when a debate does not reach an agreement.

Empty replies: they take place when architects tell designers to review the document provided without offering any further information.

Interaction analysis, that is, the process of requesting information and providing a reply, provided the basis for defining classification according to the effect of each interaction in the development of the project. The following are the categories identified during the analysis of interactions on the part of researchers:

Informative interactions: those geared toward information transfer.

Correction-gearred interactions: they generate the need to reflect and study on the part of architects. They seek modifications on the solutions and choices originally proposed during the architecture stage.

Clarifying interactions: they are geared toward explaining and complementing a description.

Self-correcting interactions: they help architects find errors that need to be identified. They are different from correction-gearred interactions because they do not take place after requests by designers.

Empty interactions: those where there is not any valuable information exchange.

Argument interactions: those that generate debate between architects and designers.

Corrective-collaborative interactions: they are geared toward correction and rise from a designer's proposal, rather than from a designer's request.

EVALUATION OF INTERACTIONS

At the beginning of the experience, a high percentage of clarifying, informative and correction-gearred interactions take place. This can be explained given the low quality of initial descriptions by architects, in terms of clarity and completeness. In most cases, low levels of writing skills were identified. The highest percentage of interactions was that of correction-gearred interactions, which indicates self-regulation by groups. In time, self-regulation became evident through Self-correcting interactions, which means that architects themselves identified their own errors as a result of receiving inquiries by designers while reviewing architectural proposals by other groups. The need to put proposals in writing in order to facilitate comprehension became evident as well. This gradually strengthens communicative abilities.

The analysis of Figure 1 makes it possible to verify that, in time, there was a decrease in clarifying, informative and correction-gearred interactions. This indicates that the corrections made provided adequate responses to feedback by designers, providing them with appropriate tools to carry out their implementation work. Debates or argument interactions emerged mostly when both designers and architects had acquired conceptual tools to assume a stance and defend it, as well as to recognize their own errors. All groups showed a tendency to reach consensus. Role-plays permitted learning to evolve, which was observed

in Corrective-collaborative interactions that took place when both roles had enough conceptual elements to carry out a debate. The design group could make proposals and, together with the architects, they found the best solution to develop each project. This was verified in the project assessment meetings, where both architects and designers were present.

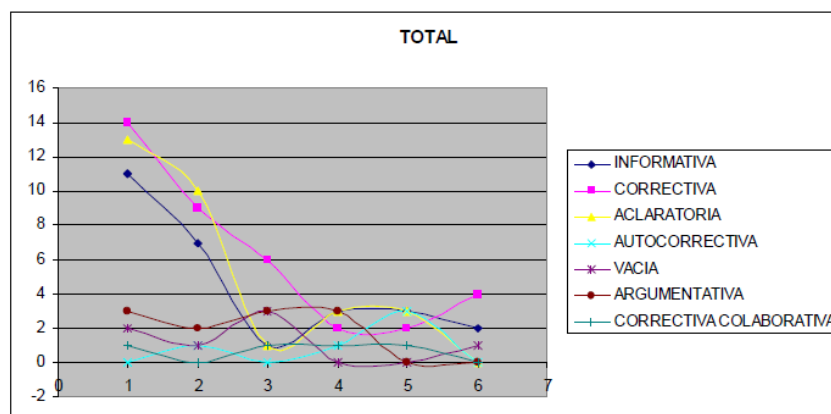


Figure 1. Interaction patterns

Architectural proposals which were adequate since the beginning did not require many interactions, since they were clear and complete. This could be seen in the interaction forum. On the other hand, a number of proposals needed several modifications during the activity due to their defects or conceptual errors.

It is worth stressing that, by the end of the process, all the designs were fully functional and met the requirements previously established. This makes it possible to infer that all the groups evenly reached objectives at the level of content, and that they attained course objectives in a collaborative way. This does not mean that all the architectural proposals and the organization of the systems presented were identical, since each architect/designer pair found solutions with significant differences. The main differences were proposed at the level of the internal organization of the blocks that constitute each system.

EVALUATION RESULTS

The experience in the Digital Design subject was evaluated by students through self-reports that dealt with achievements made in terms of motivation, collaborative work and learning. Students had to evaluate each one of these factors based on a scale from 0 to 5.

Response percentages were calculated based on the number of responses given by all of the students who carried out the evaluation (70). The grade obtained on each factor evaluated corresponds to the average grade given by students.

Factor No. 1: MOTIVATION. Average grade: 4.53/5

Among the three factors evaluated by students (motivation, collaborative work and learning), motivation got the highest grade. This can be seen through an increase in attendance and participation on the part of students. The effective use of class time was also a motivating factor due to timely clarification processes, to access to relevant information in the forum, and to the use of the tools available both in classrooms and the laboratory.

Factor No. 2: COLLABORATIVE WORK – Average grade: 4.35/5

Collaborative work received the second best grade in this evaluation process. Students particularly identified the strength and usefulness of interactions between work pairs and between students and the teacher. This explains the increase in participation. A number of

students developed motivation toward team work and, in general, there was an atmosphere of collaboration and respect among participants.

With regard to communicative processes, students emphasized both the clarifications provided by the teacher and the efficiency of the process. This facilitated comprehension and concept assimilation. Technology and software tools played an important supporting role in these information exchanges.

Factor No. 3: LEARNING – Average Grade: 4.3/5

Class didactics contributed to learning, particularly in the practical application of concepts. Students stressed the usefulness of student-teacher interaction, since they could timely obtain clarification about key concepts for the development of the project.

Access to information obtained the third place among the factors that favor learning. It enriched interactions and was managed so that information would be, not only transmitted, but understood and applied to the solution of problems.

CONCLUSIONS

Conclusions are given at three levels. First, the contribution of this CDIO experience in the training of students through an exercise which is similar to the situations engineers normally face in their work life. Second, the impact of this proposal on motivation toward learning: it fosters autonomous learning, as an essential personal competence. The third aspect is the contribution of this process to the assimilation of concepts, which became evident in the results shown by the groups involved. Conceptual clarity was evident in both discourse and written reports.

Concerning the contribution by this experience, results make it possible to state that the proposal promotes the development of skills which are considered fundamental in the curriculum for future performance in Digital Design. Students assume the roles of architects and designers, which are involved in real situations, and enhance both writing and debating skills through written reports and forum discussions.

The importance of collaborative learning also becomes evident, since it contributes to the identification of individual strengths and to joining efforts. Collaborative work is an essential element in the development of interactions between work pairs, and helps in the assessment of the nature of intervention by students. Even though at the beginning there is a high number of communications geared toward correcting the work carried out by other people, and toward requesting information, the process here described evolves into self-correcting interactions.

By the end of the process, most designs are successful. This reflects the importance of collaborative work between work pairs in order to make progress in learning, concept assimilation and problem-solving skills. Each architect/designer pair creates and implements solutions which propose alternative paths of action that respond to the objectives established for the project. This stimulates creative and divergent thinking, as well as a change in the understanding of the discipline itself.

Among the three factors evaluated by students during this experience (motivation, collaborative work and learning), the one with the highest rating was motivation. Students showed an increase in attendance to class sessions, a higher level of participation in activities, and a better performance during the tasks assigned. It also has a positive impact on concept assimilation and work quality.

It is worth emphasizing what students pointed out concerning the importance of timely feedback on the part of the teacher and immediate access to relevant information, which are directly related to the comprehension and assimilation of technical concepts. These are two key factors that make it possible to go from a mere transfer of information to a real comprehension process which helps solve problems, developing the professional attributes of an engineer. The role of technology in this kind of experience is also stressed, since it is a supporting tool that permits a better use of class time. Likewise, technology makes it possible to share individual contributions and feedback with the whole group.

The interactions between students are important evidence of the transformations that can be generated through an experience of this nature. The process begins mainly, with interactions of informational nature, and then problems of conceptual clarity and writing-reading problems are evident. As the project develops, the predominant interactions are corrective and argumentative type. At the end of the project, most of the interactions are self-corrections, showing that the concepts have been learned.

A particularly important achievement was the writing practices of students, who could make a metacognitive view of their forms of writing, when their receptors became obvious confusion in the text of the instructions. This situation helped to achieve greater precision in the specifications, so that gradually the records of the interactions between students can see a decrease in corrections and a more favorable response from the designers to meet the specifications of architects.

Finally, this work assumes the challenge of creating conditions for keeping the quality of results during the time frame assigned to the goals proposed. It also stresses the importance of strengthening interaction processes between pairs. There is a high need of both curricular changes and transformations in teaching practices, which tend to be deeply rooted in the individual experiences of teachers and in the story of the discipline itself.

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TAKING CDIO INTO A CHEMICAL ENGINEERING CLASSROOM: ALIGNING CURRICULUM, PEDAGOGY, ASSESSMENT

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ABSTRACT

There are three major processes in education – curriculum, pedagogy, and assessment. Most reform movements focus on either the curriculum or the assessment. We believe that in order for any educational reform to be truly effective, all the three processes must reflect corresponding changes simultaneously. In fact, contemporary educational research literature strongly advises that these three processes have to be aligned in support of each other. This paper describes one approach to achieving greater alignment between curriculum, pedagogy, and assessment in a particular subject of study in a chemical engineering course at Curtin University using the CDIO framework. The paper has three sections. The first section highlights the curricular reform strategy established at Curtin University's Department of Chemical Engineering using the CDIO model. The second section describes at length how a suitable teaching and learning framework and a corresponding assessment and feedback mechanism were synthesised to reflect the aims of curricular reform. The concluding section briefly highlights the findings from a pilot study using the CDIO model undertaken in January – June 2010. This investigatory pilot study was undertaken in a final year unit called Risk Management. The preliminary findings suggest that the overall satisfaction from this unit was pleasingly very high. This has led us to conclude that from an implementation stand point the engagement of the CDIO curricular reform in the department of chemical engineering has been productive. It has enabled us to develop a coherent framework that combines teaching, learning, assessment and feedback mechanisms to address industry needs for graduates with improved competency in professional skills such as problem-solving, critical thinking and interpersonal communication skills. The classroom implementation undertaken as a pilot study has promoted the emergence of a cooperative learning environment for the achievement of unit learning outcomes. Investigation in the form of thorough unit and course evaluation will be undertaken in the near future.

KEYWORDS

CDIO Syllabus, Adapting CDIO approach, Curriculum Alignment, Learning outcomes, Learning and Teaching Framework, Assessment Methodology.

INTRODUCTION

There are three major processes in education – curriculum, pedagogy, and assessment, and according to Robinson and Aronica most reform movements focus on the curriculum and the assessment [1]. We believe that in order for any educational reform to be truly effective, all the three processes must reflect corresponding changes simultaneously. In fact, Pellegrino (cited in [2]) insists that these three processes have to be aligned in support of each other. This paper describes one approach to achieving greater alignment between curriculum, pedagogy, and assessment in a particular subject of study in a chemical engineering course at Curtin University using the CDIO framework. The paper has three sections. The first section highlights the curricular reform strategy established at Curtin University's Department of Chemical Engineering using the CDIO model. The second section describes at length how a suitable teaching and learning framework and a corresponding assessment and feedback mechanism were synthesised to reflect the aims of curricular reform. The concluding section briefly highlights the findings from a pilot study using the CDIO model undertaken in January – June 2010.

CONTEXTUALISING CDIO CURRICULUM REFORM IN CHEMICAL ENGINEERING

For well over 25 years the Department of Chemical Engineering, at Curtin University, has been engaged in preparing competent chemical engineers for work in Australia and overseas. These industry ready graduates were the result of a traditional engineering curriculum with a distinctly practical orientation. The department shares a long and rich tradition of close association with the Western Australian chemical, process, mining, and resources industries through continual consultation, research collaboration and industry-academic consortia. In 2008, the above engagement with industry affiliates revealed the expectation for graduates with even stronger problem solving, critical thinking and interpersonal skills. King's [2] report, published in 2008, *Engineers for the Future: addressing the supply and quality of Australian engineering graduates for the 21st century*, strongly echoed this demand. Hence, these warranted attention and more importantly action by the University department. Since 2008 the department has been actively engaged in exploring some recommendations of this report in its pursuit of best-practice chemical engineering education. For example, we were particularly drawn to King's recommendation that engineering educators should endeavour to explore and adopt systematic and holistic educational design practices with learning experiences and assessment strategies that focus on delivery of designated graduate outcomes based on pedagogically sound, innovative and inclusive curricula [2].

The existing traditional curriculum was no longer adequate to address the contemporary industry concerns for improved graduate competency. The need was for improved professional skills such as critical thinking, problem solving and interpersonal skills. The problem with a traditional curriculum was that it heavily gravitated toward content and knowledge acquisition. It was clear that curricular reform was necessary and timely. The emphasis of our reform would have to rest on the embedding of appropriate learning opportunities for the development of professional skills alongside mastery of disciplinary knowledge throughout the four year chemical engineering undergraduate course. With this in mind, the CDIO curricular reform model appeared a best fit owing to its equal emphasis on

technical content and professional and personal skills useful to engineers. It offered us the opportunity to translate engineering skills and abilities into appropriate learning outcomes that can be addressed in specific subjects of study (or units, as they are known in the Australian educational system) within a four year engineering course.

The undergraduate chemical engineering course at the department is accredited by the Institution of Chemical Engineers (IChemE), in the U.K. The IChemE aims to recognise and share best practice in the university education of chemical and biochemical engineers [3]. It was important that the initiative to adopt the CDIO curricular reform would simultaneously endeavour to maintain our accreditation status and sustain teaching and learning standards. We found it imperative to establish a working relationship between the CDIO and the IChemE in order to proceed. In our understanding, the CDIO approach promotes the notion that learning activities are crafted to support explicit pre-professional behaviours [4]; and the IChemE's accreditation guide [3] explicitly states exactly what pre-professional behaviours can be expected of good quality chemical engineering students. The IChemE accreditation guide offered broad guidance on disciplinary content whilst the CDIO learning outcomes provided a "a pallet of potential solutions" [4] to fulfil IChemE chemical engineering degree course expectations. The next logical step in this reform process was the mapping of learning outcomes between CDIO and IChemE so as to enable a critical engagement with both. Although the results of this mapping process are available in an earlier publication by Karpe and Maynard [5], they have been reprinted here, with permission of the authors, to support the following discussion in this paper.

In Table 1 the IChemE Learning Outcome Descriptors are provided. In Table 2 the CDIO Syllabus Topics at Level 2 detail are mapped against IChemE Learning Outcome Areas (as described in Table 1). This mapping was based on the same principles used to map the CDIO Syllabus to the ABET Student Outcomes by Crawley et al [4].

Table 1
IChemE Learning Outcomes Descriptors taken from the Accreditation Guide

	IChemE Learning Outcome	Descriptors
A	Underpinning mathematics and sciences (chemistry, physics, biology)	Students' knowledge and understanding of mathematics and science should be of sufficient depth and breadth to underpin their chemical engineering education, to enable appreciation of its scientific and engineering context, and to support their understanding of future developments
	Core Chemical Engineering	Students' knowledge and understanding of the main principles and applications of chemical engineering. Areas of learning include: Fundamentals, Applied quantitative methods and computing, Process and product technology, Systems, Process safety
	Advanced Chemical Engineering (Breadth and Depth)	In terms of depth IChemE expects Masters level student with a deeper understanding than previously acquired from first exposure to a topic earlier in the degree programme, taught to Bachelor level standard. In terms of breadth IChemE expects Masters level student with exposure to topics additional to those that would normally be considered as core chemical engineering.
B	Engineering Practice Skills	Graduates must understand the ways in which chemical engineering knowledge can be applied in practice, for example in: operations and management; projects; providing services or consultancy; developing new

		technology
C	Design Practice Skills	Chemical engineering design is the creation of process, product or plant, to meet a defined need. It includes process design and troubleshooting, equipment design, product design and troubleshooting, and system design. Students develop their powers of synthesis, analysis, creativity and judgement, as well as clarity of thinking.
D	Embedded Learning (Sustainability, SHE, Ethics)	Students must acquire the knowledge and ability to handle broader implications of work as a chemical engineer. These include sustainability aspects; safety, health, environment and other professional issues including ethics; commercial and economic considerations etc.
E	Embedded Learning (General Transferable Skills)	Chemical engineers must develop general skills that will be of value in a wide range of business situations. These include development of abilities within problem solving, communication, effective working with others, effective use of IT, persuasive report writing, information retrieval, presentation skills, project planning, self learning, performance improvement, awareness of the benefits of continuing professional development etc.

Table 2
CDIO Syllabus Topics mapped against IChemE Learning Outcome Areas

CDIO Syllabus Topic	IChemE Learning Outcome	
Technical Knowledge & Reasoning	1.1 Knowledge of Underlying Sciences	A
	1.2 Core Engineering Fundamental Knowledge	
	1.3 Advanced Engineering Fundamental Knowledge	
Personal & Professional Skills & Attributes	2.1 Engineering Reasoning & Problem Solving	E
	2.2 Experimentation & Knowledge Discovery	E
	2.3 Systems Thinking	C
	2.4 Personal Skills & Attributes	C, E
	2.5 Professional Skills & Attitudes	D, E
Interpersonal Skills: Team & Communications	3.1 Teamwork	C, E
	3.2 Communications	
	3.3 Communications in Foreign Languages	-
Conceiving, Designing, Implementing & Operating Systems in the Enterprise & Societal Context	4.1 External & Societal Context	C,D
	4.2 Enterprise & Business Context	B
	4.3 Conceiving & Engineering Systems	B,C,D,E
	4.4 Designing	C
	4.5 Implementing	B,D
	4.6 Operating	B,D

Once the mapping process was completed it was easier to develop an understanding of how best to incorporate the CDIO learning outcomes into various units of study across the four-year chemical engineering course. This exercise resulted in the creation of the Intended Professional Skills Progression Table (see Table 3)

Table 3
Intended Professional Skills Progression over 4-yr Bachelor degree in Chemical Engineering

CDIO Syllabus Topic		Y2/S1	Y2/S2	Y3/S1	Y3/S2	Y4/S1	Y4/S2
Technical Knowledge & Reasoning	1.2 Core Engineering Fundamental Knowledge	Process principles	Process engineering analysis	Process modelling & simulation	Process synthesis & design	Risk Management	Design project
Personal & Professional Skills & Attributes	2.1 Engineering Reasoning & Problem Solving	3	3	3	4	4	4
	2.2 Experimentation & Knowledge Discovery	2	2	3	4	4	4
	2.3 Systems Thinking	2	2	3	3	4	4
	2.4 Personal Skills & Attributes	2	3	3	3	4	4
	2.5 Professional Skills & Attitudes	2	2	2	3	3	4
Interpersonal Skills	3.1 Teamwork	3	3	4	4	4	4
	3.2 Communications	2	3	3	3	4	4

The Intended Professional Skills Progression table is the basis of our reform strategy. The primary goal of undertaking curricular reform was to create and distribute learning opportunities for the development and refinement of professional chemical engineering skills and abilities within the disciplinary curriculum. The intention was to embed learning activities within IChemE guided disciplinary content such that student engagement with these curricular activities would provide practise of specific professional skills through achievement of CDIO learning outcomes. Our reform initiative was motivated by the need to address the industry demand for improved problem-solving, critical thinking and interpersonal skills. The left-hand side of the table incorporates specific CDIO syllabus topics we feel readily address our reform requirements. On the right-hand side of the table, core chemical engineering units of study are listed in vertical text. These units have been selected based on the IChemE guidelines for disciplinary content. Above each of these units is an indication of the year and semester in which these units will be delivered. For example, the unit, Process engineering analysis is taught in the second semester of the second year of the course; and the unit, Process modelling and simulation is taught in the first semester of the third year. In the Australian engineering education system, the first year of study is common to all engineering disciplines. This common first year, also known as Engineering Foundation Year (EFY) has a separate curriculum, distinct from disciplinary curriculum, and its design and implementation is done by different teaching and development team. This is the reason why the first year of engineering study is not included in table 3.

The numbers in the cells represent the expected student proficiency level based on the CDIO proficiency scale as suggested by Crawley et al [4]. For the purpose of clarity the rating scale linking the numbers or "scale points" to the corresponding levels of competence expected in the activities or experience of engineers is presented below.

1. To have experience or been exposed to;

2. To be able to participate in and contribute;
3. To be able to understand and explain;
4. To be skilled in the practice or implementation of;
5. To be able to lead or innovate.

Some assumptions have been made in order to arrive at these scale points within table 3. For example, it is assumed that the students entering their second year of study have had personal experiences in applying skills emphasised in the Intended Professional Skills Progression table, not just those resulting from within the context of their foundation year but also non-academic, social settings. A scale point of 2 has been chosen for personal skills and attributes of students entering year two, based on consultation with the EFY teaching and learning teams. Realistically the ability to lead or innovate will only come with several years of experience as a practicing engineer. It is much more reasonable to expect that students would graduate skilled in disciplinary practices so as to secure gainful employment. For this reason, a scale point of 4 has been chosen during the final semester of final year.

The aim of this paper is to describe how we have used the CDIO framework to approach the notion of better alignment of curriculum, pedagogy, and assessment to ensure effective curricular reform. The next logical step of our curricular reform journey was to implement the CDIO framework to examine whether our reform objectives could be sufficiently addressed in particular units of study. For this purpose, a pilot study was to be conducted in 2010, in the unit of study – Risk Management. It is taught in the first semester of the fourth year of the engineering course (see table 3). The following section describes at length how a suitable teaching and learning framework and a corresponding assessment and feedback mechanism were synthesised to achieve the aims of curricular reform using CDIO.

LEARNING, TEACHING, ASSESSMENT, FEEDBACK: SYNTHESIS OF A SOUND FRAMEWORK

Robinson and Aronica [1] believe that most educational reforms focus either on curriculum or on assessment. They contend that these reforms fail because the policy makers believe that in education the best way to face the future is by improving what they did in the past. What this means is that, for example, ineffective assessment reforms are succeeded by more assessment reforms. Not enough attention is given to all the components that comprise the educational system. Stark and Lattuca (cited in [6]) draw our attention to the fact that what we call the curriculum is in fact a complex phenomenon. They appeal for the recognition and exploration of the interdependence of the elements within this complex phenomenon. It is important here to unpack the implications of Stark and Lattuca's appeal. What are the elements of a curriculum? In what way are they interdependent? We felt it was important to understand the elements of an engineering curriculum and how they are interrelated because it would better enable us to determine the most appropriate course of action to take reform straight to where it mattered most, the engineering classroom. Cornbleth (cited in [6]) reminds us that our conceptions and ways of reasoning about curriculum reflect and shape how we see, think, and talk about, study and act on the education made available to our students. Cornbleth's statement validated our decision to better understand the elements of the engineering curriculum we were keen to reform.

Curricula in higher education are, to a large degree, hidden curricula, being lived by rather than being determined [7]. According to Barnett, curricula have an elusive quality about them; their actual dimensions and elements are tacit; they take on certain patterns and relationships but those patterns and relationships will be hidden from all concerned, except as they are experienced by the students [7]. What does this mean? In the contemporary educational context the curriculum is something that the educational institution concerns itself with. The course leaders of the institution design the curriculum. This curriculum is then

experienced on a daily basis by the subjects of the institution, its enrolled students. This experience takes the form of classroom interactions and other specifically designed learning activities which address certain learning outcomes. Student engagement with learning outcomes leads to the fulfilment of curricular intentions. In reality though, it is never so simple. Curricular intentions take the form of broadly defined graduate attributes, or more particularly, refined explicit learning outcomes for specific units of study. But having a well-designed curriculum or well-stated learning outcomes is only a small part of successful education practice. The eventual success of the curriculum rests largely in what happens within classrooms. This is where the elements of this hidden curriculum co-mingle and give rise to the complexity of teaching and learning disciplinary knowledge and skills.

Let us take a moment to understand what this means. It is important to note that educational institutions emphasising knowledge and skills acquisition are largely prevalent. But Dall'Alba and Barnacle point out the curricula designed by these institutions raises the question of how such knowledge and skills are to be integrated into skilful practice, or more broadly, contribute to the transformation of the learners [8]. Dall'Alba and Barnacle believe that students are not assisted and supported in situating and localising knowledge within specific manifestations of practice; a focus on knowledge acquisition leaves to students the difficult task of integrating such knowledge into practice [8]. In other words, whilst the university (or school or department) expects students to engage in the acquisition of disciplinary knowledge, principles and concepts, there is little promotion of *how* to actually learn such complex domain knowledge, appreciate it, and subsequently effectively apply it. What is the implication of the above statements in our context? Our curricular reform must not only expect the students to improve their problem-solving, critical thinking and interpersonal skills, but also attempt to establish and elaborate what this actually entails, and how these can be exercised. It is the department's responsibility to provide organisational and cultural support for learning oriented practices involved in the development of professional engineering skills.

Claxton identifies that the key to educational reform lies in the culture as it is experienced, day in, day out, by the students [9] He recommends that real reform actually needs to take place in the classroom ethos and methods, and the assumptions that underpin them. In our understanding, Claxton is suggesting that curricular reform needs to affect the culture of learning, teaching, assessment and feedback within the classroom. These form the elements of the curriculum that interplay within the everyday classroom environment. A survey of contemporary higher education literature will confirm that these represent the visible dimensions of any hidden curriculum.

Ritchhart (cited in Claxton [9]) makes a pithy observation, which we personally identify with:

“We’ve come to mistake curricula, textbooks, standards, objectives, and tests as ends in themselves, rather than as means to an end. Where are these standards and objectives taking us? What is the vision they are pointing toward? What purpose do they serve? What ideals guide us?...Without ideals, we have nothing to aim for. Unlike standards, ideals can’t be tested. But they can do something standards cannot: they can motivate, inspire and direct our work.”

We felt these are questions worth considering in our endeavour to adopt the CDIO standards and model. Why did we concern ourselves with educational reform? Our personal response to this question is: Learning does matter; and so do our Learners. The act of learning is meaningful and productive only if the learner willingly engages in it. Savin-Baden observes that for those of us who have designed courses that enable students to meet the learning outcomes expected by benchmarking standards, the university and the professional body the challenge then is to equip the students to take up the challenge of taking control of their

learning [10]. The IChemE believes that chemical engineering education needs to stimulate and develop student talents and that the university degree programmes must communicate the relevance and excitement of our profession [3]. The IChemE concedes that high quality chemical engineering degrees are demanding on students [3]. We agree with this view. It is also the reason why we share Savin-Baden's previous sentiment about challenging students to take engage in self-directed learning. Without passionate self-directed engagement in learning, such high expectations will merely prove to be onerous, not just for the students but also those enthusiastic educators who facilitate quality learning. For, little of value is achieved without effort, although a great deal more is achieved with impassioned effort. The reason we're pursuing the CDIO curricular reform is so that it may be "enthuse, engage and inform students" [11], and that the learning activities can possibly enhance our students' "relationship to their learning and the content they are learning about" [12].

How do we promote self-directed learning? Robinson and Aronica believe that it is possible when we put students in an environment where they want to learn [1]. Dewey (cited in [13]) recommends that when we give students something to do, not something to learn; and the doing is such a nature as to demand thinking, or the intentional noting of connection; learning naturally occurs. Keeping this recommendation in mind, our next question focused on what type of learning by doing would be appropriate for the study of Risk Management. The nature of this disciplinary domain would reveal our answer. The IChemE accreditation guide recommends that this topic be considered integral to the study of chemical engineering systems, and expects students must be able to understand the principles of risk and safety management, and be able to apply techniques for the assessment and abatement of process and product hazards [3]. Risk Management textbooks suggest how the subject ought to be engaged for the purposes of learning. Cameron and Raman propose that an undergraduate introductory course needs to emphasise principal concepts of risk management and the practical outworkings of those concepts [14]. Skelton deems it necessary to show undergraduates how safety assurance is actually performed in industry [15]. Skelton recommends that students move gradually from simple application of common sense and basic engineering skills to application of specialist safety analysis methods [15]. Based on the above recommendations it was determined that learning within this unit of study be distinctly application oriented. It was to provide ample opportunities for students to mobilise their thinking skills, transfer and apply prior knowledge such as vacation work experience and internship, engage and exercise their engineering sensibilities and powers of judgement, and actively make connections between chemical and process engineering theory and practice in the context of real-world scenarios and situations.

Using the Intended Professional Skills Progression table (see table 3) as a reference and combining the IChemE guidelines and Risk Management textbooks recommendations we chose specific CDIO syllabus topics that could be addressed through appropriate learning activities. Table 4 provides a mapping of the Risk Management Unit Learning Outcomes to their corresponding CDIO syllabus topics at levels 1, 2 and 3.

Table 4
Definition of Risk Management Unit Learning Objectives (ULOs) mapped to corresponding CDIO Syllabus topics at Level 1, 2, and 3.

Unit Learning Outcome	CDIO syllabus topic at level 1	CDIO syllabus topic at level 2	CDIO syllabus topic at level 3
Risk Management Principles and Concepts	Technical Knowledge and Reasoning	Core Engineering Fundamental Knowledge	-
Reasoning and Problem Solving	Personal & Professional skills and attributes	Engineering Reasoning and Problem Solving	<ul style="list-style-type: none"> • Problem Identification & Formulation • Estimation and Qualitative Analysis • Solutions & Recommendations.
Knowledge Discovery	Personal & Professional skills and attributes	Experimentation and Knowledge Discovery	<ul style="list-style-type: none"> • Hypothesis Formulation • Survey of Print and Electronic Literature • Hypothesis Test, and Defence.
Systems Thinking	Personal & Professional skills and attributes	Systems Thinking	<ul style="list-style-type: none"> • Thinking Holistically • Emergence & Interactions in Systems • Prioritization & Focus
Critical Thinking	Personal & Professional skills and attributes	Personal Skills and Attributes	<ul style="list-style-type: none"> • Critical Thinking • Awareness of One's Personal Knowledge, Skills & Attitudes • Lifelong Learning
Teamwork	Interpersonal Skills	Teamwork	<ul style="list-style-type: none"> • Team Operation
Communication	Interpersonal Skills	Communication	<ul style="list-style-type: none"> • Communication Structure • Oral Presentation and Inter-personal Communication

How does this table help us in the classroom context? The CDIO concept promotes the notion that learning activities can be crafted to support explicit pre-professional behaviours [4]. The unit learning outcomes represented on the left-hand side of table 4 highlight the knowledge and skills we consider relevant for effective study of Risk Management. Activities involving the CDIO syllabus topics at level 3, on the right-hand side, can then be crafted to achieve the corresponding unit learning outcomes. For example, activities emphasising problem identification, solutions and recommendation can be designed to address the unit learning outcome relating to engaging reasoning and problem-solving skills. It is also possible to design activities that address more than one unit learning outcome at the same time. For instance, students can operate in small teams to undertake a hypothesis defence for a particular problem scenario. Teams can engage in oral presentations with other teams to argue and defend their respective hypotheses.

For the purposes of this unit, the problem-based learning approach was considered most conducive to facilitate effective engagement with the specific CDIO level 3 syllabus topics. PBL proponents and practitioners have published extensively about its benefits including its ability to develop professional competencies, higher order thinking skills, interpersonal skills, and an understanding of how to apply knowledge, and hence improve quality of learning [16-23].

Bearing in mind the unit learning outcome and the corresponding CDIO level 3 syllabus topics, appropriate learning activities were determined. These learning activities could be favourably grounded in the problem-based learning approach. The chosen learning activities and their theoretical rationale based on contemporary educational research literature is represented in Table 5.

Table 5
Risk Management Learning Activities and their Theoretical Rationale

Learning Activity	Rationale
<ul style="list-style-type: none"> • Homework problem • In-class group problem • In-class test 	<ul style="list-style-type: none"> • Learning starts with and occurs through engagement with authentic ill-structured problems [16].
<ul style="list-style-type: none"> • Reflective Journal for Food for Thought 	<ul style="list-style-type: none"> • Learning processes of enquiry which proceed by asking what needs to be known to address and improve a particular situation [20]. • Critical reflection is central to effective action [20].
<ul style="list-style-type: none"> • Concept Map 	<ul style="list-style-type: none"> • Assisting students to visualise the structure of the subjects they study, that is, the links between concepts [24].
<ul style="list-style-type: none"> • In-class group-facilitator discussion on Food for Thought • In-class group-to-group presentation on In-class group problem • In-class group-to-class presentation with question-time, and facilitator feedback • In-class group-to-group peer feedback on presentation 	<ul style="list-style-type: none"> • Fostering community through group work [25]. • Learn how to interact with different people and systems and learn to rely on their advice and knowledge [26]. • Opportunities to get learners to evaluate reasoning [27]. • To make visible to students to see the ontological, epistemological and methodological dilemmas [27] involved in resolution of authentic ill-structured problems.

In this unit of study all the learning activities were deemed assessable. This strategy acknowledged two important educational research recommendations. The first being that assessment is fundamental to the teaching process and that the time during assessment could and should be used as an excellent time for learning [24]. The second recommendation promotes the notion that the process of assessment provides a natural opportunity to bring both content and process objectives together and that process skills can be demonstrated and assessed as an integral part of assessing content knowledge [18]. Table 6 provides an indication of how each individual learning activity can provide address specific unit learning outcomes in Risk Management. For example, the homework problem will require engagement of disciplinary knowledge, reasoning and problem solving, and knowledge discovery skills. The in-class group presentation activity will effectively engage reasoning and problem-solving using disciplinary knowledge and team operation and communication skills.

The learning activities were interactive. This way it was possible for the facilitators (lecturers and tutors) to provide immediate feedback to students in most cases. Learning requires feedback [28]. Our stance on providing feedback was based on a sound recommendation by

Price, Handley, Millar and O'Donovan that in an environment espousing a focus on the development of independent thinkers, feedback can only be positioned as advice rather than instruction [29]. Table 7 presents our feedback mechanism for Risk Management.

Table 6
Risk Management Unit Learning Outcomes mapped to Learning Activity/ Assessment Type

Unit Learning Outcome	CDIO Syllabus Topic Level	Homework Problem	Reflective Journal	Group Problem	Group Presentation	Concept Map	Test
Risk Management Knowledge	1.2	X		X	X	X	X
Reasoning & Problem solving	2.1	X		X	X		X
Knowledge Discovery	2.2	X		X			
Systems Thinking	2.3		X	X		X	X
Critical Thinking	2.4.4			X			X
Lifelong learning	2.4.6		X			X	
Teamwork	3.1.2			X	X		
Communication	3.2.2 3.2.6		X	X	X		X

Table 7
Feedback Mechanism for Risk Management

Rationale for Feedback	<ul style="list-style-type: none"> Feedback can only be positioned as advice rather than instruction [29]. Students' ability to make sense of and use feedback can be improved through classroom discussion of improvements students intend to make [28]. 	
Learning Activity	Time of Feedback	Method
Food for Thought	Weekly, in-class	Dialogic, group-facilitator interaction
Reflective Journal	Weekly, in-class	Written, and dialogic (if appropriate)
In-class presentations	Weekly, in-class	Written, and dialogic, in the form of peer and facilitator responses
In-class tests	In-class feedback sessions a fortnight after each test	Dialogic, and written (available upon student request)
Concept Map	Currently we are unable to provide sound feedback. A concept map analysis software is under investigation to generate useful insights on student learning.	

REFLECTIONS AND FINDINGS

According to Boud (cited in [30]), at the end of the day what makes a difference is exactly what a student does and how they experience what they do. In February-June 2010 a pilot study was undertaken to implement the CDIO model within a chemical engineering unit of study named Risk Management. We had a class with 133 enrolled students. In the course of implementing our approach we encouraged students to engage in providing us on-going feedback on the teaching and learning experience. During the semester spanning 14 weeks with an actual teaching period of 12 weeks, we secured this quality-as-experienced feedback in week 4, 12 and 14 in the form of student learning satisfaction questionnaires and unit evaluation surveys. The student learning satisfaction questionnaire was designed by the second author, whilst the unit evaluation survey is a university designed instrument named "eVALUate". The response rate for the student learning satisfaction questionnaire was 100% since all the enrolled students (133) attended the final class in week 12 and willingly shared their views on the learning experience. The response rate for the eVALUate is 42% since these are collected at the end of the semester at which time a majority of the students are either unavailable or uninterested in any university related activities until next semester. It is beyond the scope and intent of this paper to examine and analyse the effectiveness of our approach. The preliminary findings suggest that the overall satisfaction from this unit was pleasingly very high. Most students appreciated the interactive learning activities such as group discussions and found the group presentations beneficial. Concerns were raised regarding the utility of concept maps and reflective journals as learning tools. Some students found traditional pedagogic methods better suited to cover technical aspects of this unit of study. This could be attributed to differences in learning styles, motivations, or resistance to alternative methods that demand heavier learner engagement. A large majority of students found the homework and group problems as effective means to learn in this unit. Most students were receptive to the fact that the unit's learning activities encouraged active thinking. A vast majority of the students strongly appreciated the feedback they were receiving throughout the learning experience and how it was helping them understand the unit better.

The preliminary findings led us to conclude that engagement of the CDIO curricular reform in the department of chemical engineering has been productive. It has enabled us to develop a coherent framework that combines teaching, learning, assessment and feedback mechanisms to address industry needs for graduates with improved competency in professional skills such as problem-solving, critical thinking and interpersonal communication skills. The classroom implementation undertaken as a pilot study has promoted the emergence of a cooperative learning environment for the achievement of unit learning outcomes. Investigation in the form of thorough unit and course evaluation will be undertaken in the immediate future.

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ENTREPRENEURSHIP IN ENGINEERING: BRIDGING THE GAP BETWEEN ACADEMIA AND INDUSTRY

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ABSTRACT

Every year thousands of college students work on projects coming up with great ideas and lots of new technology. The problem is that many of these projects are abandoned upon graduation and filed away in someone's office, never making it to market where it could be profitable for both the students and universities. This paper looks at the things being done at the University of Colorado that help students develop their technology further so that it is able to make it into the business environment. Companies like eSpace and organizations affiliated with the university like RASEI as well as programs like the Engineering Management certificates, are crucial in helping students with their ideas. The focus will be on the HELIOS team and their idea and how they were able to develop it further. Starting as a senior design team in the Fall of 2009 students developed an innovative hybrid propulsion system for small aircraft. Using the previously mentioned resources they performed market research and started a new company TIGON EnerTec, Inc. Tigon will move the idea from a project to a product.

KEYWORDS

Startup Company, hybrid engine, entrepreneurship, TIGON EnerTec

INTRODUCTION

Engineering students have no trouble conceiving, designing, building and testing cutting edge technology. Research and school projects force students to be creative and innovative in finding solutions to real life problems. A lot of these solutions have potential to be sold commercially, but coming from an academic environment as opposed to a business environment, these technologies typically fall into what entrepreneurs call the "valley of despair". Most engineers lack the business skills and experience necessary to take a technology from the research stage to the market. Fortunately for students of the University of Colorado there is a vast network of assistance available to students and faculty aimed at promoting entrepreneurship. This paper discusses the evolution of a student project that developed a hybrid-electric engine for use in UAV platforms. Students saw that their innovation had a potential place in the market and sought assistance from The Center for Space Entrepreneurship (eSpace) and the Renewable and Sustainable Energy Institute (RASEI) in order to make it across the so-called "valley of death". Through this process the students refined their technology, identified potential markets and recognized market "pains", protected their intellectual property, gained valuable business skills, built a strong team, incorporated a company, and sought out investors.

THE IDEA

The Senior Design class at the University of Colorado is a two semester capstone program in which an industry engineering environment is very well simulated. Students must work together in teams on real-world problems and come up with a solution all while learning how to manage time, integrate complex systems, test and document effectively, and manage financial resources. In fall '09, Professor Jean Koster presented his vision of a hybrid-electric aircraft to the HELIOS Senior Design team. The team spent a great deal of time brainstorming many different systems configurations for a hybrid system. Thinking outside the box, the team came up with a device that efficiently combines torque from two independent power sources and outputs the power to a single propeller shaft. The HELIOS team designed, manufactured and tested the hybrid propulsion system while a team from Daniel Webster College in Nashua, NH designed an airframe specifically intended for the propulsion system. In spring '10 the teams integrated the two systems and successfully flew their hybrid engine for the first time. Figure 1 shows the launch of the HELIOS engine in the solar powered airframe developed by Daniel Webster College.



Figure 1. First launch of HELIOS Hybrid-Electric Engine

FINDING A MARKET

After realizing that the team had created an innovative and creative solution to hybridizing small aircraft, one engineering student from the HELIOS team partnered up with an MBA student from the CU Business School under the guidance of a local entrepreneur as a part of RASEI's Market Assessment Program. The program lasted four months in which both students investigated various markets in which the hybrid engine might be profitable. Patent searches and analysis were performed in order to determine whether or not the technology was the first of its kind. It was found the hybrid engine design did not infringe on any existing patents. Seeing that the hybrid design was unique, the students then brainstormed on how to sell it. The MAP program taught the students to think outside the box when looking for potential markets. In addition to commercializing the engine in the unmanned aerial vehicle (UAV) market, the students found that their technology could show profits in the RC hobbyist market, the general aviation market, marine and boating market, and the ATV/motorcycle market. Each of these markets was

analyzed in great detail in which the students determined the size and the potential share that a company selling the engine would have. Of all the markets investigated, the UAV market appeared to be the most promising entry point for a small company. Unmanned vehicles are becoming more and more popular as they provide a cheaper and safer way to carry out missions that are traditionally carried out by manned aircraft. The following chart from The Teal Group depicts the projected procurement of UAVs over the next decade.

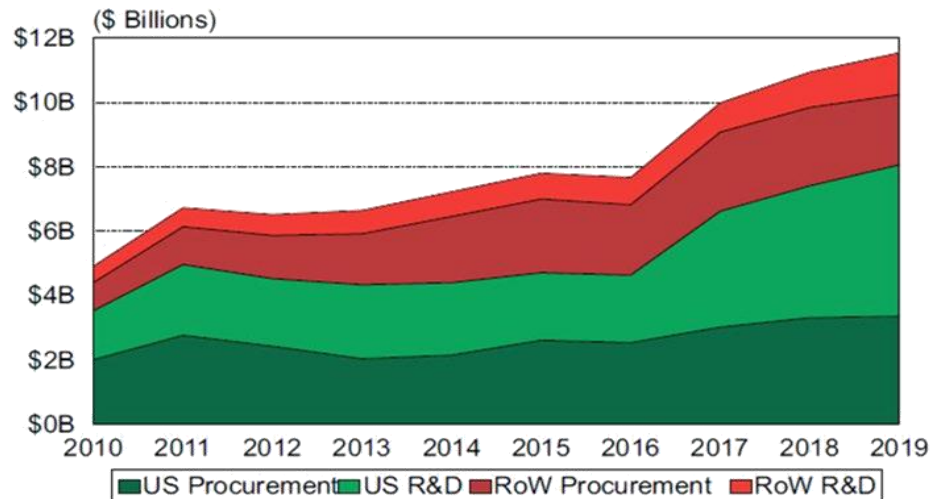


Figure 2. Projected UAV Market [1]

This chart numerically predicts that sales in the UAV market will increase dramatically in the coming years. In addition, a report by Frost and Sullivan shows a lack of understanding of current UAV propulsion in that “Of all the platform technologies in UAVs, the engines or power plants remain the most sought after and least investigated” [2]. At the end of the MAP program, the students were even more excited about the hybrid engine design than ever before as they had evidence that their technology would fare well in the commercial marketplace. Subsequently RASEI saw the potential as well and gave additional funding to begin the process of starting a company.

BUILDING THE RIGHT TEAM

It has often been said that the management team of a startup company is just as important as the product the company is selling. In order to be successful, the team knew that they must form a team that has a solid technical knowledge base, a strong entrepreneurship motivation, and a wealth of industry contacts. The four students involved: Alec Velazco, Derek Hillery, Cody Humbargar, and Eric Serani were all graduate students in Aerospace Engineering Sciences at the University of Colorado. They held the necessary technical knowledge as they were the students responsible for designing and refining the hybrid-electric engine. Dr. Jean Koster provided additional technical knowledge and as an excellent link to the academic world. Dr. Koster was able to promote the technology through his network and attract the attention of many interested parties.

Although the team's technical skills were strong, they still lacked a leader. Many interviews were held until the team found the right person for the job. Les Makepeace, a retired navy pilot, former production lead for the F/A-18E/F at Boeing, leader of various early stage startup companies, and serves as Adjunct Faculty for Entrepreneurship at the Daniels College of Business, University of Denver. He filled in the missing pieces of a strong management team with his vast connections to the military and aerospace companies and his previous experience with entrepreneurship. With a solid foundation, the team incorporated their company, TIGON EnerTec, Inc. in the fall of 2010.

PROTECTING INTELLECTUAL PROPERTY

The results of the MAP program showed that the hybrid-electric engine design was something truly unique. In order for the team to enter the market as the first hybrid UAV propulsion system manufacturers the intellectual property had to be protected. The Technology Transfer Office (TTO) at the University of Colorado handles patent filings for university developed knowledge. TTO let the students of the original HELIOS team decide whether they would like to file the patent themselves or let the university handle it. Since most of the original team was graduating and heading off in various directions and lacked the finances necessary to file a US patent, they decided it would be easier if the patent was filed through the university. During the patent process it was of utmost importance that the team kept the technical design out of the public eye. This process resulted in the filing of two US patents on the hybrid technology in December of 2010.

BUILDING BUSINESS SKILLS

An additional service offered by the University of Colorado to help engineers bridge the "valley of despair" is the Engineering Management Program. Sponsored by Lockheed Martin, the Engineering Management Program provides an education to those seeking a career in management opportunities in engineering and technology. One of the certificates offered with this class is the engineering Entrepreneurship Certificate. This certificate is offered in partnership with the Deming Center for Entrepreneurship. It provides the student with the essential knowledge, understanding and skills to successfully practice entrepreneurship in a start-up venture.

The focus of the Engineering Entrepreneurship certificate program is on how to launch, lead and manage a viable business starting with concept validation to commercialization and business formation. The program culminates with the development of a business plan for a project you choose that you then pitch to business community leaders and venture capitalists. The undergraduate curriculum is comprised of four core courses totaling 12 credits.

The first course focuses on leadership and management where the students learn some of the essential skills in leading a team. We also looked into personality types using Myers-Briggs and determined how to best get different personalities to work together. The second course was focused on finance and accounting. This allowed us to get an overview and understanding of where it was that the money was actually going. The third class was focused on high technology marketing. This introduced us to how we need to go about marketing a new

invention such as the one found in HELIOS. The final class was a Business plan preparation course. This course brought together all the previous courses into one capstone project in which teams of six were formed. These teams are comprised of both business and engineering students who develop a business opportunity.

For this course, members of the HELIOS team decided to focus on their hybrid propulsion system and continue developing it into a business. In this class students go through an industry analysis, marketing and operations plan. They also developed a financial and funding plan. These were then all refined and united into one overall business plan that was then presented to industry leaders and venture capitalists. The judges were very impressed with the HELIOS opportunity and were awarded first prize in the class for business plans. Overall this certificate was imperative in preparing students for starting a company and introducing students to what they did and did not know about business.

THE NEXT STEPS

With these things completed the team set off on forming the company, TIGON EnerTec, Inc. Armed with the right team and the market research, the team opened its first round of investing to start raising money. The goal is to raise \$2MM in equity to allow for all development supporting broad commercialization in the UAV, General Aviation, and motorcycle markets. The TIGON hybrid solution is inherently fast and cheap to integrate, therefore a \$2MM equity round allows two years of working capital and broad commercialization.

TIGON has the exclusive license to develop, commercialize and sell a hybrid propulsion technology that drastically reduces the time and cost associated with developing a hybrid vehicle. Already demonstrated in the aerospace market, TIGON will continue commercialization work in aerospace while expanding the technology into marine applications and small land vehicles. TIGON is poised to capitalize on the performance gap between traditional propulsion and electric propulsion by offering an affordable alternative with benefits from both traditional and electric systems.

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Quantifying the Efficiency of Project-Based Learning Experiences

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ABSTRACT

This paper examines methods by which the efficiency of Project-Based Learning experiences can be quantified. One specific area of interest is the cost per student per project as a function of the number of learning outcomes for that project. The paper uses four Project-Based Learning experiences that have been offered to two different groups of students over the past two years as a test-bed for the investigation. Although quantitative results still need to be processed, instructor observations, project economics and student comments reveal that more significant learning outcomes are achieved when a project is both technically challenging and the technology is observable. For the projects examined in this investigation the more expensive projects were found to result in the more significant learning outcomes.

INTRODUCTION

The use of active learning, and specifically Project-Based Learning (PjBL), has been shown to be an effective means of increasing the development of attributes that would otherwise be difficult to enhance in a traditional engineering curriculum [1]. Teamwork, interpersonal communication, engineering economics, and dispute resolution are all examples of attributes that can be developed and strengthened through the PjBL experience. The utility of these dual-impact learning experiences is that they help strengthen not only the hard-to-reach attributes but also reinforce technical understanding of the particular subject area that the PjBL experience relates to [2,3]. Although there are many positive aspects surrounding the PjBL experience, the fact remains that they can be expensive to implement given the requirements for non-traditional hardware and infrastructure, the additional expenses for the materials and supplies required for each project, and the additional instructor time required in preparing for the activity, running the activity, and in post-activity assessment.

Engineering educators and administrators need to have methods of assessing the tradeoff that exists between the enhanced value in the form of learning outcomes that result during a PjBL experience with the additional financial investment required to offer that experience. It is with this view that this paper examines different methods of quantifying the efficiency of PjBL experiences. Efficiency itself is a broadly-defined term that is traditionally dimensionless; however, in this paper several different indicators are developed that indicate the "efficiency" of a PjBL experience. With these indicators an engineering educator would then be better positioned when deciding which PjBL experience to offer in a course.

The paper will include analysis of PjBL experiences in Renewable Energy that were offered in a collaboration involving the University of Calgary and Shantou University (STU) during two

consecutive years [4], May 2010 and again in May 2011. During each program year a total of forty students were divided into eight groups of five students per group, and each group was given a one-week long PjBL experience that nominally required approximately 16 hours of laboratory time to complete. Teams were randomized from week to week in an attempt to remove biases that come from team unification through repeated group activities. During the May 2011 PjBL experience team members were asked to complete a survey that quantified the learning process, including the level of difficulty of each step of the exercise, the level of involvement (number of tasks per team member), the level of learning associated with non-technical attributes, and the level of learning associated with technical attributes. This information, combined with financial aspects associated with the cost of each project, provides input data with which the different efficiencies can be quantified.

Given that the 2011 program only concluded on 28 May 2011, it was not possible to process student survey results in time for this paper. This paper will instead discuss aspects of the survey design, the economics of the four PjBL experiences, and instructor observations that were made as a result of a small but significant changes between the May 2010 and May 2011 program that help interpret activities within the student teams.

BACKGROUND

As discussed in the introduction, PjBL experiences offer dual impact learning experiences, helping to strengthen traditional engineering skills itemized in CDIO Syllabus Categories 1 *Technical Knowledge and Reasoning* and 4 *CDIO in the Enterprise and Social Context*, but also providing mechanisms by which CDIO Syllabus Categories 2 *Personal and Professional Skills and Attributes* and 3 *Interpersonal Skills: Teamwork and Communication* can also be strengthened.

Although there are obvious benefits associated with PjBL experiences, Prince [5] points out that it is important to determine if the benefit of the active-learning exercise is significant and that the benefit of the activity needs to be considered in terms of the extra effort or resources required to achieve this benefit. Roselli and Brophy [6] use classroom observations, student surveys and knowledge-based questions to show that active learning can help students to better understand more difficult concepts in a course.

On the topic of the effectiveness of laboratory learning, both Campbell et al. [7] and Abdulwahed and Nagy [8] found that improved learning results when students are exposed to simulation-based learning prior to coming to the physical laboratory. Both papers highlight the shortcomings of standard laboratory-based instruction and highlight the benefit of student-motivated learning for laboratory-based courses. Although this paper does not use simulation-based learning, it does involve a laboratory-based course entitled Renewable Energy Practicum where groups of students design, implement and operate their own experiments. This type of approach to learning is more expensive than the courses described in References [7, 8] that involve the use of simulation-based instruction, thereby prompting the desire to quantify the efficiency of the learning outcomes more accurately.

One major driver in determining the efficiency of a project is group size. Griffin et al. [9] examine the impact of group size on learning outcomes in a capstone design course. Too large a group size results in free-riding and social loafing while too small a group size can impede the ability to innovate by restricting the diversity of past experience. In the context of the current

investigation, too large of a group size can result in free riding however too small of a group size can result in unreasonable expectations with too large a workload. Group size also has implications on permanent infrastructure costs as well as materials and supplies costs. Griffin et al. [9] conclude that for a capstone design course group size should not exceed 6 students due to the presence of free riding in larger group sizes.

METHODS

A one-week pilot project was performed in February 2009 involving 30 Schulich School of Engineering (SSE) students and 30 STU students working in teams of 7-8 students on a single implement-operate project. This model of student exchange proved very successful, providing a hybrid between an international project and an international field trip [10] and the 2009 exchange provided motivation for developing the Renewable Energy Practicum course [11].

The Renewable Energy Practicum course consisted of four implement-operate exercises and two field trips. All of the exercises included both a build phase and a testing phase. Students were put in teams of 5 students, and student teams were altered for each exercise. Teams consisted of a mix of SSE and STU students, and gender balance was ensured for all teams. The exercises consisted of: i) construction and testing a solar-photovoltaic cell [12]; ii) construction and testing a solar fan [13]; iii) construction and testing of a wind turbine [14]; and, iv) construction and testing of a solar-thermal water heater [15]. Each implement-operate exercise was taken from the project-sharing website Instructables (www.instructables.com) [12-15]. The Instructables website provides step-by-step instructions on how to build a wide array of devices, and consequently it proves to be a very useful resource when planning implement-operate exercises.

Project Descriptions:

1. Solar Photovoltaic Cell: this project involved fabrication and testing of a copper-cuprous oxide photovoltaic cell. A copper plate heated on a hot plate resulted in the formation of a fine cuprous-oxide layer on the surface of the copper plate. The plate was then mounted in a case filled with a water / baking soda mixture. An electrical circuit was completed through the addition of a second copper plate, with the completed cell shown to the left in Fig. 1. This project was relatively simple and provided a gentle introduction for the students to both the workshop and the nature of the implement-operate projects. *Learning Outcomes:* mechanical design; photo-voltaic effect in a copper-cuprous oxide thin-film solar cell; simple soldering; efficiency estimation.



Figure 1. Solar Photovoltaic Cell (left) and Testing of the Cell (right)

2. Solar Fan: this project involved the use of two solar cells and two NiCd batteries (1.2V and 600 mAh) from commercial garden lights. The solar cells were used to charge the batteries during the day, and at night the charged batteries were used to power a 12 V (0.15A) computer fan. Use of two 1.2 V batteries to power a 12 V fan requires the use of a Linear Technologies micropower DC/DC converter (LT1073). The circuitry and fabrication in this project were more complex than the first project, requiring the students to be both organized and focused. An example of a final project is shown to the right in Fig. 2. *Learning Outcomes:* mechanical design; energy storage; power conditioning; soldering techniques; circuit assembly.

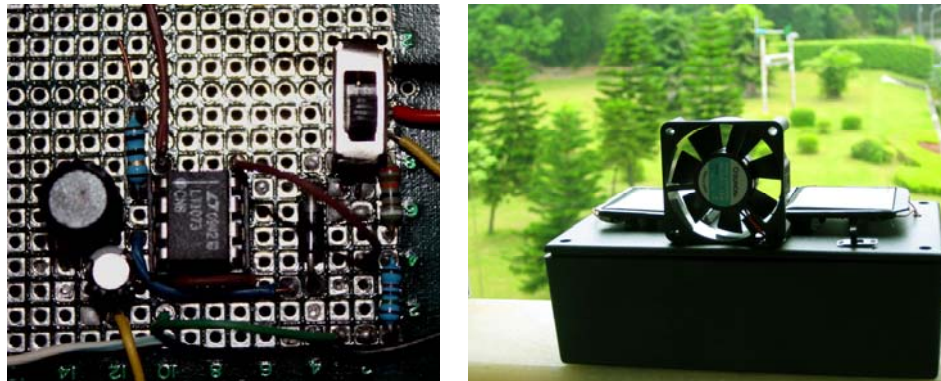


Figure 2. LT1073 DC/DC Converter circuit (left) and Solar Fan project (right)

3. Wind Turbine: this project involved the fabrication and testing of a vertical-axis wind turbine of the Savonius rotor design. The most complicated aspect of this project involved the fabrication of the electrical generator. Eight rare-earth permanent magnets (NdFeB) were mounted to the rotating Savonius turbine, and twelve generator coils were fabricated by winding aluminum bobbins using either 32 AWG or 36 AWG magnet wire. This project proved to be the most challenging given the complexity of the generator section. Placing it during the third week was optimum as students had honed both their mechanical and electrical skills in the two previous projects. Testing was performed at speeds up to 10 m/s in the Shantou University wind tunnel laboratory (3 m X 2 m test section; 45 m/s max velocity), as shown in Fig. 3. *Learning Outcomes:* mechanical design, wind turbine power curve; AC generator design; rectification of an AC voltage to a DC voltage; power estimation; designing an experimentation test plan.



Figure 3. Operating wind turbine (left) and students in the STU Wind Tunnel (right)

4. Solar-Thermal Water Heater: this project involved the fabrication and testing of solar-thermal water heater that mimicked the performance of an evacuated tube collector. Students fabricated the water heater using nested plastic bottles. Reflective tape was used to increase the concentration ratio of the collector. A simple child thermometer was used to measure the temperature of the water within the heating section, as shown to the right in Fig. 4. This was the simplest project and it was placed at the end of the course during the week with the least amount of time for the Practicum course. The students were skilled in the workshop by the final week and consequently the building phase of the project was completed in the first day. *Learning Outcomes:* mechanical design; solar-thermal energy systems; efficiency estimation.



Figure 4. Solar-thermal water heater designs (left) system testing (right)

Instruments and Measures:

As mentioned earlier, due to the fact that the May 2011 course ended on 28 May 2011, it was not possible to review the student surveys prior to writing this paper. Instead of performing detailed analysis of the student survey results, this paper will provide a summary of the instruments and measures used and offer some limited insight based on the data and information available at the time of writing. A future CDIO paper will offer more concrete data analysis.

1) *Team Project Review Survey*

In order to quantify the PjBL learning process, a short (8 question) survey was developed. As noted previously, this survey was completed by students at the end of each one-week long PjBL experience, and was intended to report on the level of difficulty of each step of the exercise, the level of involvement (number of tasks per team member), the level of learning associated with non-technical attributes, and the level of learning associated with technical attributes.

The survey was developed to be general enough so that it could be used for a wide range of projects, yet specific enough to allow PjBL experiences to be quantified. As well, we felt that it was important to use the same survey questions for each project for consistency: i.e., both in terms of making the questions familiar to students, as well as allowing for consistent analysis of the results.

To accomplish this, the survey, shown in Fig. 5, involved very general questions that could be linked back to each specific project. For example, Questions 1 and 7 focus on the level of difficulty of each step of the exercise. These questions do not assess the level of difficulty

directly, but instead ask students to quantify their level of activity on the project. “Level of difficulty” is very subjective and would vary from student to student based on their background as well as on how project tasks were shared among team members (e.g., some team members may be assigned less or more difficult tasks than others). However, by linking back to the number of steps involved in project, a relative level of activity per step can be translated into a level of difficulty for the project. This, in combination with student feedback on team size (Q 7), provides insights into the level of difficulty of each project (e.g., more difficult projects require more students).

Questions 2 and 3 tackle the level of involvement of students in a team setting. Rather than asking students to quantify the “number of tasks per team member”, we chose to quantify a more general “level of involvement”: i.e., asking students to quantify the number of tasks completed would have overly complicated the survey and would have likely proved to be unreliable (e.g., difficult for students to identify what constitutes a task). The more general questions on each student’s contribution to the team, in combination with the instructor’s knowledge of the number of steps for the project, result in a more reliable estimate to the level of involvement for individual students.

Team project review:					
<i>For each statement, select a number from 0% to 100% to indicate your degree of agreement with the following statements (please check one response for each statement).</i>					
	Disagree			Agree	
How strongly do you agree with the following statements:	0%	25%	50%	75%	100%
1 My level of activity on this project was high.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2 I made important contributions to my team.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3 My team's project would <u>not</u> have been completed on schedule if I was absent.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4 I learned new non-technical skills (e.g., communication, team work, etc.)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5 I learned new technical skills in the specific project area.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6 This project helped me understand the technical area more than if I had only relied on lecture notes and a textbook.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7 Our team had the right number of students for the scope and allotted time.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Based on your answer to statement 7, please indicate how many more or less team members you feel your team needed (please only answer 8a or 8b).</i>					
	1	2	3	4	5
8a My team needed ## <u>more</u> members.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8b My team needed ## <u>less</u> members.	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 5. Team Project Review Survey

The level of learning associated with technical and non-technical attributes is addressed by Questions 4-6: Questions 4-5 focus on new skills, while Q 6 focuses on the mode of learning (i.e., PjBL vs. traditional lecture notes and textbook). For this aspect of the survey, Questions 4-5 are linked directly to the intended learning outcomes for each project. For example, the Wind Turbine project performed by the University of Calgary / Shantou University students involved electric generators and full-wave rectifier circuits. Although the basic theory should not have been new to the students, the PjBL exercise led some students to new insights into power losses in practical electrical circuits. When viewing the survey results in the context of the project learning outcomes and the classroom assessments (e.g., team presentations and answers to questions), it becomes clear when and where new technical and non-technical attributes are gained for the project.

2) Project Budgets, Learning Outcomes and Quality of Learning Outcomes

The budgets for each of the projects included one-time equipment costs as well as materials costs required each time a project was performed. The costs will be reported on a per team basis assuming 8 teams. The cost of a Dremel high speed hand tool is included as a one-time cost for each project. The number of learning outcomes are estimated based on the nature of the exercise. The quality of the learning outcome is assessed by the instructor after giving consideration to the complexity and challenge of the project, the time taken to complete the project, and the nature of student comments made in relation to the project. The Wind Turbine Project often resulted in students stating that it was the best experiment that they have encountered in their undergraduate careers, consequently it received a *High* rating in the Quality of Learning Outcome column. It should be pointed out that the costs of testing in the Shantou University wind tunnel laboratory were not included in the project economics.

Table 1
Project Budgets, Number and Quality of Learning Outcomes

Project	One-Time Cost (\$ / team)	Materials Cost (\$ / team)	Learning Outcomes	Quality of Learning Outcomes	Hours to Complete Project
Solar Cell	\$122.50	\$0.81	4	Low	4
Solar Fan	\$87.50	\$42.87	5	Medium	8
Wind Turbine	\$87.50	\$108.40	6	High	8-10
Solar Thermal	\$22.50	\$2.17	3	Low	2-4

OBSERVATIONS AND DISCUSSION

Until the survey data has been processed and analyzed it is difficult to make specific conclusions about the relative efficiency of the projects. Based on instructor observations, however, it was noted that the more complex and involved a project, the more interested the students became. This was noted most for the Wind Turbine project where the complexity of the build operation was such that most team members needed to be involved. Although the Wind Turbine took a similar amount of time to complete as the Solar Fan, the Solar Fan involved the use of an Integrated Circuit (DC/DC Power Converter) and the students found the abstractness of the Integrated Circuit less appealing than the exposed and explicit nature of the AC generator in the Wind Turbine.

Although teams of 5 were prescribed, it is presumed that smaller teams may result in more significant learning outcomes. This comment can be supported by considering that in May 2010 students were not required to write a report documenting the build and test procedures, while in May 2011 such a report was required. It was observed that during the May 2011 course offering teams would assign one of the 5 members as the "note taker," a person who would type the build and test procedures on a laptop while the lab activity was taking place. Given that all projects were completed on time with one of the five members not engaged in the build-test cycle, it is possible to conclude that the group sizes could have been reduced from 5 to 4 students per team and still reach the goal of building and testing the device. Discussion with one of the students in the course supported this observation.

A third observation is that although the Solar Cell and Solar Thermal project were the most cost effective, they were characterized by lower student interest. The number of Learning Outcomes for both projects were also lower, and consequently the Quality of the Learning Outcomes was assessed as Low for both projects.

One other modification made during the 2011 course offering was to add two new dimensions to the grading rubric for the project report. The new dimensions assigned points for Innovation in both the Design and Testing process. The Design dimension states "The development makes 2 or more innovations beyond what was originally described that assist in system performance" while the Testing dimension states "The testing quantifies the performance of the system by exploring two or more variables." The addition of these two dimensions encouraged the students to think beyond the instructions provided by the Instructables website and helped keep them more engaged.

CONCLUSIONS

This paper has made a first attempt to quantify the efficiency of four project-based learning experiences. A survey instrument has been developed to help assess student involvement and learning outcomes for the PjBL experiences. Although the study is still in the early stages and no quantitative results have yet been obtained, qualitative results indicate that the more involved the project the more interested the students become. According to the results found by other researchers, it is speculated that this will result in stronger learning outcomes. This does not mean that the projects with lower learning outcomes should be removed from the course as these projects help serve an important purpose by gradually introducing students to more general topics including workshop safety and lab conduct.

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PROFESSIONAL PRACTICE AND DESIGN: KEY COMPONENTS IN CURRICULUM DESIGN

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ABSTRACT

This paper describes the development of a new engineering curriculum at Massey University. The new curriculum is an innovative approach to engineering education in New Zealand and will be a point of difference from other providers of engineering qualifications. A comprehensive curriculum architecture has been developed around a project based spine allowing appropriate technical disciplinary linkages to be made through design and build activities and where professional skills are emphasised. Active learning experiences are developed throughout the integrated curricula. The CDIO Standards are used as a benchmark for this new curriculum and provides an opportunity for reflection and improvement. Through an effective redesign it is envisioned that the new degree will be attractive to prospective students, will enable more engagement and retention during their education and will produce graduates that are highly sought after by industry.

KEYWORDS

Engineering curriculum design, project based learning, benchmarking, graduate profile.

INTRODUCTION

Engineering and technology programmes have been offered at Massey University for over 40 years. For the past few years, student numbers have been static. This, combined with a lower recognition of Massey Engineering in the student market, prompted the School of Engineering & Advanced Technology (SEAT) executive to review its strategic direction. Pivotal to this, was the definition of a compelling value proposition and clearly defined point of difference from other providers of engineering qualifications in New Zealand.

Coincidentally, at the same time as SEAT was embarking on its strategic review, the International Engineering Alliance's (IEA) Graduate Attributes and Professional Competencies [1] adopted by the Washington, Sydney and Dublin Accords required signatories to review their current standards. Within New Zealand, this prompted the Institution of Professional Engineers New Zealand (IPENZ) to formulate the National Engineering Education Plan [2] defining the gap between IEA's graduate exemplar and the current IPENZ accreditation criteria and graduate profile. The key outcomes were:

- There is a need for professional engineering graduates who are "rounded" and not just technical boffins – many of the existing graduates do not have strong "soft" skills.

- Professional engineering graduates should aspire to leadership roles, and their education should equip them to commence their preparation towards such roles.
- Graduates entering industry have technical knowledge that is largely theoretical, and industry needs to invest considerably to close off the knowledge gap between principles as taught and codified knowledge as used in industry.
- Graduates entering industrial research roles are educated in insufficient depth towards the frontiers of knowledge.

New Zealand's nearest neighbour, Australia, through Engineers Australia, has also recently undertaken a revision of their Stage 1 competency standards, which has also taken into account the Threshold Learning Outcomes developed by the Discipline Scholars in Engineering and ICT; under the Australian Teaching and Learning Council's Standards and Assessment project [3]. What is pertinent about this project's resulting learning standards is the emphasis on the professional skills. There are five standards which are built on a strong knowledge base:

1. needs, context and systems
2. problem solving and design
3. abstraction and modeling
4. coordination and communication
5. self management [4]

It is quite clear that the professional associations within NZ and Australia are changing their expectations of graduate engineers. This change, combined with SEAT's student enrolment and market recognition challenges, provided the context and focus for its strategic review. Central to this review has been the re-design of its undergraduate degree programme (BE re-design).

In general, whilst the technical ability of graduates was not in question, it was apparent that the current programme lacks emphasis on professional practice attributes, and the wider contextual aspects of engineering practice. Interestingly, these aspects were at the very core of engineering at Massey University during the 1980's and 1990's, where there was great alignment to industry through such practice. During the last decade this 'industry connectivity' has been eroded due to the strong driver for faculty to focus on research.

In mid 2010 a Working Group, led by the director of teaching and learning, involving faculty representing all majors (i.e. disciplines) within the BE(Hons), has been setup. The programme is a four year honours degree which consists of four majors: chemical and bioprocess engineering (CBE), electronics and computer engineering (ECE), mechatronics (MEX) and product design engineering (PDE). The redesigned BE(Hons) is targeted for launch in February 2012.

In the early stages of the BE re-design, the CDIO syllabus was identified as a model against which to benchmark SEAT's new curriculum developments. Rather than apply the CDIO templates directly, it was decided to focus on the issues facing the engineering students and graduates in New Zealand, and specifically engineering at Massey University, and to compare the resulting findings with the CDIO syllabus.

This paper presents the method used to design the BE curriculum that is intended for launch next year. It outlines the decisions made during the curriculum design and the consequent benchmarking against the CDIO Standards.

THE BE RE-DESIGN PROCESS

The key focus of the Working Group was on addressing those issues that were contributing to recognition and reputation of the degree programme, and its attractiveness to key stakeholders – current students, potential students and employers. Industry feedback from individual companies and SEAT advisory board, together with information from student focus groups identified the following core issues:

A clear point of difference and strong value proposition. There are a number of providers of tertiary engineering education in New Zealand. Although, in earlier years, Massey University held a strong and well defined position in this market, over recent time this strength has been largely eroded. The visibility and recognition of Massey Engineering has declined and with it the reputation of its undergraduate degree programme.

Professionally relevant curriculum. Feedback from a 2009 Institution of Professional Engineers of New Zealand (IPENZ) accreditation highlighted the need for greater alignment with IEA graduate attributes and professional competencies. Significant deficiencies were identified in the current curriculum. Additionally, student feedback pointed to a real lack of attractiveness and student engagement. In particular, the lack of integration of fundamental knowledge into active learning situations was highlighted.

Engaging delivery. The current programme is centred on traditional lectures with large numbers of students. Modes of knowledge delivery and application are outdated, resulting in an environment and culture lacking real energy, vitality and enthusiasm.

To bring all this together and communicate it to the key stakeholders a comprehensive marketing campaign is required. In parallel with the BE re-design a complementary marketing campaign has been developed to communicate the core value proposition and point of difference. The strap line OBSERVE INVENT REALISE forms the basis of the campaign with associated visual images used as reinforcement. Biomimicry images were chosen to underpin the principles of observe, invent, realise. The observe invent realise message and associated images are being applied to a range of marketing collateral – booklet covers, billboards, busbacks, business cards etc. Besides the obvious external marketing benefits, this campaign is already having an internal effect on staff and students through providing a sense of pride, focus and unity.

Defining the Point of Difference and Value Proposition

Through industry consultation SEAT identified the need to focus on producing graduates who were “industry ready”, had strong problem solving skills and who could work effectively in a multifunctional or multidisciplinary environment. These characteristics not only met current industry needs but they are also well aligned with the new professional engineering requirements.

The term OBSERVE, INVENT, REALISE was coined to represent the fundamental ethos of SEAT and of its graduates. It also defined the key point of difference and value proposition for the School and its graduates:

Observe – taking an active interest in all that surrounds us and linking this to engineering principles.

Invent – creatively apply our engineering & contextual knowledge to the solution of problems; today and in the future.

Realise – ensure that our inventions are focused on social or commercial wealth creation.

Whilst the Observe, Invent, Realise mission statement portrays an ethos for the School’s operation, not just in undergraduate teaching but through its research and day-to-day

activities, it is necessary to emulate this through to the graduate profile of the BE(Hons) programme. There are three defining attributes of the graduate:

Embedded Knowledge

- Our graduates can effectively apply the knowledge that is at the FOREFRONT of their discipline, built on UNDERPINNING science and in-depth TECHNICAL capability to solve complex engineering problems that industry faces today and in the future.

Design and Achieve

- Our graduates are able to creatively and systematically solve complex problems that are both challenging and contemporary to industry and ensure that the solutions are focused on social and/or commercial wealth creation.

Professional Practice

- Our graduates have honed skills that allow them to continually develop professional skills, knowledge and intuition through self-reflection and an urge for lifelong learning.

The outward demonstration of this profile is the inherent ability of graduates to observe, invent and realise. These are not simply words, they are at the very heart of the graduates thinking processes and mode of operation.

To ensure that faculty, students and industry can easily connect with what the programme is trying to achieve the Working Group decided to present the graduate profile as an illustration. Figure 1 shows the profile, which has been adapted from Taiichi Ohno's Toyota Production System house [5].

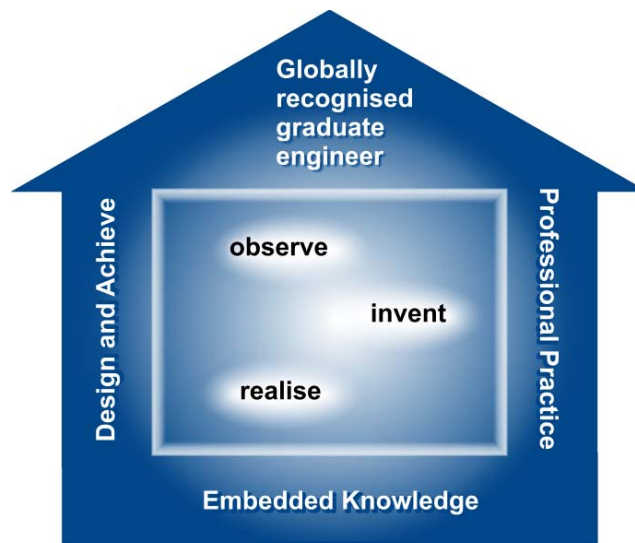


Figure 1. Graduate profile for a Massey University Engineer

The foundation of the house must be sound thus the core knowledge that supports each major is imperative. However, technical knowledge alone cannot produce an engineer without the 'walls' of design and achieve and professional practice. Take out one of these attributes (i.e. the walls and the foundation) and the roof collapses. At the heart of the house is our ethos, observe, invent, realise.

Professionally Relevant Curriculum

The tangible product – what the students experience everyday is the curriculum. When the current BE(Hons) was originally designed it had a cohesive set of courses with a clear

pathway of how each course contributed to the whole programme. It is now quite apparent that the curriculum's cohesion has been gradually eroded. It can be described as a collection of silo'd courses, which is augmented by the fact that the first year courses are not taught by faculty within SEAT. Courses such as Physics 1A, Physics 1B, Calculus 1, Programming Fundamentals, Computer Science Fundamentals, Chemistry and Living Systems, Biology of Cells and Principles of Statistics are owned and taught by faculty within the College of Sciences and these courses serve many programmes such as the Bachelor of Science and Bachelor of Veterinary Science. In addition the majority of courses focus on the developing the disciplinary skills where very little emphasis is given on incorporating wider professional practice skills.

A key focus of the BE re-design was to engage and enthuse students right from the beginning of the degree and maintain this engagement and enthusiasm throughout the 4 years of the degree. Active learning which provided application focussed embedding of knowledge was seen as central to achieving this aim.

The curriculum architecture has been developed with consultation of faculty, industry, students and alumni, using focus groups. Figure 2 pictorially represents the curriculum's structure and where the graduate attributes are emphasised. Note that letters correspond to the three defining attributes of the graduate. K represents embedded knowledge (i.e. technical knowledge and reasoning). P represents professional practice (i.e. personal and professional skills and attributes and interpersonal skills). D represents design and achieve. The progression through the curriculum is shown by year 1 (at the bottom) moving through to year 4 (at the top of the diagram).

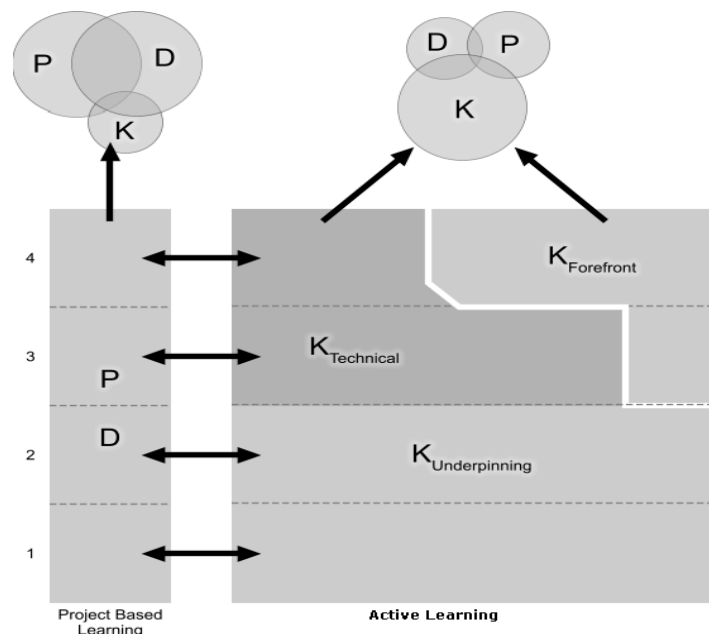


Figure 2. Curriculum Architecture and Relationship to Graduate Attributes

The application of contextual knowledge through professional practice, which enables students to develop and apply their skills in engineering reasoning, experimentation, systems thinking, personal and professional skills, communication, teamwork, and the ability to design and achieve within a societal and business context is an important facet of the new curriculum. To reinforce its importance the curriculum will have 25% (i.e. two 15 credit courses from a total of eight courses per year) aligned to achieve these attributes. Here there will be a considerable change to the instructional system to achieve this. Project-based learning (PjBL) [6] will be a core component, where it is expected that students will work in

teams to solve engineering problems by having design-build experiences that are aligned with industry and the wider society. It is important that this experience begins from day one of the programme so that students begin to appreciate what it means to be an engineer and stimulates their enthusiasm for the profession. This experience will be built on in each of the remaining 3 years where the projects will become more complex and open-ended. The details of how this is to be achieved will be outlined in a later section.

It is also expected that the problems will utilise the disciplinary technical knowledge that is obtained from other courses and is continually used and built on from year to year. It is intended that the PjBL approach contextualizes the underlying sciences and engineering technical knowledge, and equips graduates with a broader set of professional skills and attitudes. The curriculum is designed so that there will be greater emphasis on developing the professional practice (P) and design and achieve attributes (D).

The remaining 75% of the curriculum is focused on embedding the underlying sciences and engineering technical knowledge so that sufficient depth can be achieved and an opportunity to explore the forefront of the discipline through rigorous research capability. The focus here is on developing the technical knowledge and reasoning (K) although there is an expectation that P and D will also be developed concurrently, albeit to a lesser degree.

The main instructional system used here will be active learning [7] (although it could be seen that PjBL is also part of the active learning instructional system). It is apparent that the current student body is changing and teachers need to challenge their approach about traditional knowledge transmission teaching. The new curriculum expects a greater degree of active learning to take place in each course.

To ensure that this happens guidelines have been prepared that support staff in the challenging task of designing courses that ensures the learning outcomes and assessment strategies meet the required graduate attributes. Within these guidelines there are guiding principles that must be followed:

- Contextual learning should be integral to every course. Teaching should circulate between deductive and inductive processes, normally starting with a particular case, working through to a general principle.
- Active learning modes that promote knowledge acquisition, understanding, use and analysis that allows synthesis and evaluation/assessment to be accomplished (i.e. a requirement to move up the learning pyramid [8]).
- That there are clear linkages between courses and that there is a clear recognition of how courses contribute to the graduate profile i.e. specify how the learning outcomes contribute to achieving K, P and D.
- All courses must have an allowance of independent learning activity to allow for reflection and the generation of an e-portfolio.

The guidelines also encourage the use of a variety of assessment methods (e.g. observation, peer assessment, posters) as well as the more common approaches, i.e. examination, laboratory or reports. Faculty are expected to use the appropriate method to achieve the learning outcomes.

Engaging Delivery

All products need a delivery system that complements that product attributes and benefits. In the case of an undergraduate degree programme the delivery includes a range of features:

the environment and workspaces; the climate and culture of the organisation; the teaching styles and modes

The Environment and Workspaces

The redesign of the curriculum coincides with the refurbishment of SEAT's buildings and facilities. The refurbishment programme began in 2006 and initially focussed on remodelling and expanding its laboratories to allow for more space and updated equipment to facilitate hands-on learning. It is currently in its final phase with a completion date of December 2011. This final phase is focused on hub of the School, joining together different parts of SEAT to create a focal space.

The BE Working Group believes this is an opportunity to ensure that this space is used to support social learning, which will be an important part of the design-build experiences. Currently a student space user group has been set-up, which involves faculty and students to develop a plan for the effective use of this space. Its aim is:

'Create an environment within the public/student spaces that fosters pride and understanding of Massey's School of Engineering and Advanced Technology, and promotes innovation, teamwork and a sense of belonging for students and staff and can communicate the special nature of Engineering at Massey to visitors, industry and potential students.'

Initial ideas suggested are:

- Build large viewing windows in laboratories, workshops and meeting rooms that allow student activity to be clearly seen. This has actually been implemented in the earlier build phases of the refurbishment and will continue to be implemented during the final phase.
- Create a video wall capable of displaying single and multiple digital images. This would be visible from all parts of the central hub of SEAT and be the point of focus from walkways that connect all majors to the hub. For example it could display completed student projects, emerging technologies, world events and business headlines and presentations from industry.
- Create stand up (scrum) meeting venues to be used for short sharp team meetings. It is envisioned that these venues would contribute to an atmosphere of innovation and energy through the buildings. The venues could be used by both staff and students. The design-build courses would use these for break-out sessions.
- Provide low, café-style tables and chairs that can be easily rearranged to encourage more informal social interaction.

Climate and Culture

The SEAT's executive team have developed a strategy that focuses on developing faculty that are well connected with industry, have collaborative relationships, have a sound appreciation of industry needs, and undertake research to support the knowledge of future industry needs. To enable this to happen SEAT have changed the recruitment policy to put greater emphasis on an applicant's affinity with industry. The recognition and reward policy has been reviewed to have more balance between research and teaching excellence. There is more financial and academic recognition for faculty to do consultancy work. There is greater willingness and encouragement for faculty to take secondments in industry.

Teaching Styles and Modes

SEAT has also built into the budget a significant amount for faculty development in teaching and learning practices to support the change in teaching strategies. This has enabled the BE Working Group to bring in the expertise of one of the Australian Teaching and Learning

Council's Discipline Scholars in Engineering and ICT (Prof. Ian Cameron from the University of Queensland). Prof. Cameron acts as a mentor and has visited SEAT several times over the last 12 months and is crucial in providing influence and authority to support the vision.

Recently there has been a 2 day curriculum development workshop involving 40 faculty members from SEAT and from the College of Sciences (i.e. chemists, computer scientists, mathematicians and physicists). This provided the direction and approach faculty must take in designing the curriculum. Subsequently learning teams have been formed with responsibility for developing particular parts of the curriculum. All teams have been supported by training about the design process, which is using Threshold Concept Theory [9] to provide focus on content and appropriate teaching and learning strategies to tackle concepts students have difficulty with. This approach has helped faculty concentrate on the 'jewels in the curriculum' rather than trying to squeeze in as much content into the curriculum.

There is also a plan of 1 day workshops which will have a focus around a specific teaching and learning issue, e.g. assessment in PjBL, active learning in laboratories, reflective portfolio development, etc. Each workshop will have a guest speaker who has experience of the issues with an engineering and science focus and will be facilitated by teaching consultants from Massey University's National Centre for Teaching and Learning.

The development of the personal, professional, interpersonal and CDIO skills are a core component of the new curriculum by allowing students to work in teams to solve engineering problems by having design-build experiences. In the current syllabus there are two courses that specifically focus on developing these skills. One is in semester 2 of the second year and there is a capstone project in semester 1 and 2 of the fourth year. The new programme will have a double semester (30 credits) opportunity in each year to develop these skills. This block of learning is locally referred to as the "project based spine" of the curriculum.

There is a team of 5 faculty members taken from across the disciplines to develop the curriculum for this project based spine, although as it's an integrative part of the curriculum there will be iterative consultation with the wider faculty. The detailed development of this spine is currently underway and is following a specific process based on the suggestions provided by the CDIO Syllabus.

The first step in this process is to define the proficiency or competence level expected of a graduating engineer for each topic stated in parts 2, 3 and 4 of the CDIO Syllabus. The team has used the CDIO survey to identify viewpoints from industry, alumni and faculty. This is currently underway and it is envisaged that there will be 30 respondents from industry and alumni and 20 respondents from faculty.

The intention is to use the results to provide a specification of student proficiency in these skills that informs the team to develop appropriate learning outcomes using the Bloom verb patterns used in the CDIO Syllabus [10]. Although this specification of proficiency will focus on the project based spine it is intended that this proficiency statement will inform the other courses, i.e. the remaining 75% of the curriculum, of their contribution to meeting this proficiency.

The intention is to map the development of each skill throughout each of the four years of projects. For each project there will various CDIO syllabus topics that will be explicitly taught and assessed in line with the specific learning outcomes for the project. There will be defined learning outcome levels (referring to the 5 activity based proficiency levels [10]) and whether a topic is introduced (I), specifically taught (T) or utilised (U) [11]. Table 1 shows an example of what could result of this mapping exercise.

Table 1
An Example of a Proficiency Map for the Project Based Spine

Yr.	Course	CDIO Syllabus Topic													
		2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	4.1	4.2	4.3	4.4	4.5	4.6
1	Project101	T2		I	T2	I	T2	T2	T1	T2	T1	T2	T1	I	I
2	Project201	U		T2	U	U		T4		T3	T2	T3	T2	T1	
3	Project301		T2	U	U	U	T4	U		U	U	U	T3	T2	T
4	Project401	T4	U	T3	U	T2	U	U		U	T3	U	T4	T3	T

The next step in this process is to define the type of project which will allow these proficiencies to be developed in each year's project(s). Note it hasn't yet been decided whether there will be one project over the 2 semesters or a separate project in each semester. Table 2 highlights the initial brainstorming ideas of the types of projects that could be developed.

Table 2
Examples of Project Types

Yr.	Project Focus	Project Examples
1	<ul style="list-style-type: none"> Provide students with an interesting, challenging and practical project at the outset of their programme. Focus on developing self, creativity with a global context. 	<ul style="list-style-type: none"> All Majors. Engineers Without Borders Challenge. Foresighting 2050 - set the scene with changed demographics (i.e. aged) and socio-economic profiles. The smart home with implications of telecommunications, etc.
2	<ul style="list-style-type: none"> Company & industry environment focus, how companies would work. Focus on design and development, and manufacture. Constrained by cost and equipment/component availability. 	<ul style="list-style-type: none"> ECE, MEX, PDE Majors - digital and electronics circuit design. E.g. to develop a controller to sort cartons on a production line. CBE Major – develop a particular product and design the pilot plant to make it. E.g. create plant to cool down sugar solution at a particular rate. Appreciate implications of scaling up to full production
3	<ul style="list-style-type: none"> Reverse engineering. Tear down product, analyse design specification to improve functionality. Tests to prove that meet specification. Complex technical problems built on student's strength in technical disciplinary knowledge. 	<ul style="list-style-type: none"> ECE Major - design product to fit specific purpose. Eg. on-line Scotland Yard board game; an add-on to Google maps; remote controller for TV. MEX, PDE Major – Teardown of a manual system that requires automation. CBE Major – select a real life manufacturing plant, collect data and assess. E.g. boiler house – do energy balances, handle unknown data.
4	<ul style="list-style-type: none"> Near to real world/industrially based project. Using company based problems requiring multidisciplinary solutions. Emphasis is on students taking total ownership of its aim, and deliverables. 	<ul style="list-style-type: none"> The project integrates the majors. E.g. working with a brewery on plant optimisation; involving chemical, mechanical and electronic contributions to a solution of a complex industrial problem.

BENCHMARKING AGAINST CDIO STANDARDS

In order to ensure that the new curriculum is designed in a systematic and holistic manner the BE Working Group used the 12 CDIO standards [12] to benchmark the decisions made. Table 3 relates the BE re-design to the CDIO standards.

Table 3
Benchmarking Against CDIO Standards

CDIO Standard	Application to SEAT BE Re-Design	Progress Evaluation
1. Adoption of the principle that product and system lifecycle development and deployment, i.e. CDIO, are the context for engineering education.	<ul style="list-style-type: none"> • Adherence to IEA graduate attributes and professional competencies. • Inherent in the SEAT value proposition of OBSERVE INVENT REALISE. • The basis of the project based spine – 25 percent of the curriculum. 	<ul style="list-style-type: none"> • Principle well recognised and adopted in curriculum design process. Explicit within SEAT strategy and understood by most faculty. Continuing reinforcement still required through to implementation.
2. Specific, detailed learning outcomes for personal, professional, interpersonal, and product and system building skills, consistent with program goals and validated by program stakeholders.	<ul style="list-style-type: none"> • Professional practice and product and systems building skills are key elements of the graduate profile. • Program validation has been carried out directly with companies and through SEAT's industry advisory board. 	<ul style="list-style-type: none"> • Having specific learning outcomes is recognised as a key weakness in the current programme. • Preliminary development has begun but significant development and validation must be completed before launch.
3. A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal and product system building skills.	<ul style="list-style-type: none"> • A comprehensive curriculum architecture has been developed based on embedded knowledge, design and achieve, and professional practice. • Multidisciplinary and contextual focus is emphasised in the project based spine allowing appropriate technical disciplinary linkages to be made. • Formation of learning teams that ensures faculty recognise the delivery of specific technical disciplinary content in context and the integration of this content through the project based spine. 	<ul style="list-style-type: none"> • Although significant work has been done there are still a number of challenges in achieving cross faculty and cross university collaboration.

<p>4. An introductory course that provides the framework for engineering practice in product and systems building, and introduces essential personal and interpersonal skills.</p>	<ul style="list-style-type: none"> • Significant emphasis on re-focusing the first year of the curriculum away from pure fundamental sciences to scientific principles that underpin engineering. • Active learning of engineering principles with an experience of the practice of engineering is developed from day 1 through the project based spine. 	<ul style="list-style-type: none"> • It is envisaged that the adoption of an interesting and challenging project in the first year as an introduction to engineering practice is seen as essential to the successful launch of the new BE(Hons). The Engineering Without Borders Challenge has been selected as a best practice framework for this to happen.
<p>5. A curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level.</p>	<ul style="list-style-type: none"> • The project based spine will include up to 8 individual or integrated projects. These will be developed from basic to advanced levels through the level of proficiency expected and the complexity of engineering problem solving. 	<ul style="list-style-type: none"> • The basic templates for the first two years of design-build experiences have been well defined with a focus on the 1st year on social, cultural context and the 2nd year around industry/company context. • Emphasis over the next few months will be placed on the projects that will allow design-build experiences in the 3rd and 4th years.
<p>6. Workspaces and laboratories that support and encourage hands-on learning of product and system building, disciplinary knowledge, and social learning.</p>	<ul style="list-style-type: none"> • As part of the current building re-design and development, considerable emphasis is being placed on creating work spaces and an environment that promotes and encourages practical learning in a team environment. • Most projects are expected to have an industrially based context where students will be encouraged to work in a company's own facilities. 	<ul style="list-style-type: none"> • Social learning spaces will be completed by the end of 2011. • Challenge is about creating a culture around faculty and students to effectively use these spaces.
<p>7. Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills.</p>	<ul style="list-style-type: none"> • Project based learning is a core spine through the curriculum which provides the focal point for the integration of technical disciplinary and wider contextual knowledge within a framework of professional practice. • The project based spine all 4 majors will have common contextual and professional practice elements. Specific technical disciplinary focus will be major dependent. 	<ul style="list-style-type: none"> • Current focus is on developing the framework for these projects by a multidisciplinary team who are developing the development of the core contextual and professional practice content. • Further development required on the technical disciplinary content to provide specific focus each major. Industry advisory boards will contribute.
<p>8. Teaching and learning based on active experiential learning methods.</p>	<ul style="list-style-type: none"> • All courses will have active learning components. • The project-based spine will provide continual reinforcement of active and experiential learning. • Industry based projects and in-company placements during vacations will provide real-life context of professional practice. 	<ul style="list-style-type: none"> • Significant work to be done on embedding the use of active learning methods across the faculty. • Need to build a wider network of industry relationships to support active learning.

9. Actions that enhance faculty competence in personal, interpersonal, and product and systems building skills.	<ul style="list-style-type: none"> • The development of a SEAT strategy that emphasises the requirement for faculty connectivity with industry. • Revisions to recruitment guidelines to place greater emphasis on context-based engineering problem and on multidisciplinary experience and ability. 	<ul style="list-style-type: none"> • Recognised as a significant challenge given current faculty competencies. Above everything else this is recognised as the critical element for ultimate success.
10. Actions that enhance faculty competence in providing integrated learning.	<ul style="list-style-type: none"> • A significant budget has been allocated to faculty development in teaching and learning practices. • External authorities have been employed to run workshops with faculty. • Cross disciplinary teams have been established to foster greater collaboration across individual courses from different faculties. 	<ul style="list-style-type: none"> • Formulate a training programme that addresses active learning approaches, assessment, evaluation of student's and themselves. • SEAT will be a pilot for the University's Peer review scheme to be instigated during 2012.
11. Assessment of student learning in personal, interpersonal, and product and systems building skills, as well as in discipline knowledge.	<ul style="list-style-type: none"> • A working group has been established to research areas of individual and team assessment with clearly defined linkages to specified learning outcomes – both within individual courses and across years. 	<ul style="list-style-type: none"> • Recognised as an area of current weakness and will be addressed in relation to developing standard 10.
12 A system that evaluate programs against these 12 standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement.	<ul style="list-style-type: none"> • Some internal systems area available for individual course evaluation but these are relatively superficial. • Some feedback systems area available for external stakeholders – mainly informal or through advisory boards. These need greater focus and formality. 	<ul style="list-style-type: none"> • Recognised as an area of current weakness and one to be addressed over the coming year. • Develop robust systems for both internal and external feedback.

By benchmarking against the CDIO standards it is clear that there has been significant progress made in identifying what needs to be done with respect to the design of the new curriculum. However, the critical challenges that lie ahead centre on the development of the desired faculty competencies to deliver this new curriculum.

CONCLUSION

This paper has provided a summary of an approach to design an engineering curriculum that enables the integration of technical disciplinary and wider contextual knowledge within a framework of professional practice. By defining a point of difference for engineering education within New Zealand (through the new curriculum) it is anticipated that the degree will be attractive to prospective students, will enable more engagement and retention during their education and will produce graduates that are highly sought after by industry.

Benchmarking the planned curriculum against the CDIO standards had been an extremely useful exercise; highlighting areas that have been done well but also highlighting those that have fallen short. Benchmarking against an internationally recognised standard has provided confidence in the approach that Massey University has taken. It has also provided focus and a method to prioritise future activities. One particular issue that must be addressed urgently is ensuring that the current faculty capability is developed further to support a curriculum that fully engages with the integration of technical knowledge, personal, interpersonal and professional skills and CDIO.

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A MODEL FOR THE DEVELOPMENT OF A CDIO BASED CURRICULUM IN ELECTRICAL ENGINEERING

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ABSTRACT

This paper deals with a model providing a structured method for engineering curriculum design. The model is developed to show the major influencers on the curriculum design and the relations between the influencers. These influencers are identified as the engineering science, the business environment, the university environment, and the teachers and students. Each of them and their influence on the curriculum is described and the sources of information about the influencers are discussed. The CDIO syllabus has been defined as part of the basis for the Bachelor of Engineering programs at the Technical University of Denmark and this gives a strong direct impact of the university environment on the resulting curriculum in electrical engineering. The resulting Bachelor of Engineering curriculum is presented and it is discussed how it complies with the model for curriculum development. The main conclusion and recommendation is that a conscious use of the model presented in the paper can structure and improve the curriculum development in a way leading to a well founded and well structured curriculum.

KEYWORDS

Curriculum development, program development, electrical engineering, CDIO.

INTRODUCTION

The development of engineering curricula is influenced by many factors. One very important consideration is the history of the curriculum. Often curricula are developed in an incremental way by introducing changes to already existing programs in a more or less systematic way. However, sometimes it may be advantageous to revisit the curriculum development and take a fresh view on the impact of different factors influencing the development. The CDIO Syllabus described in [1] is an example of an approach to a global view on the curriculum development. It defines a set of general goals for the engineering education and it provides a method for the definition of the detailed content through the involvement of focus groups representing different stakeholders. Another model describing major influencers on curriculum development is presented in [2]. This model was developed with special emphasis on curriculum development for programs dealing with nanoelectronics and Microsystems. In this paper we discuss a generalization of the model from [2] and we show the application of

the model to the development of a curriculum in electrical engineering. The model is an attempt to capture the most important influencers on curriculum development in a structured way while keeping the model simple enough to be useful in practice without requiring comprehensive analysis work. The model has a direct parallel to organizational development as described by Leavitt in [3]. Leavitt's model for development of organizational changes contains four interrelated influencers: The tasks to be undertaken by the organization, the technology, the structure of the organization, and the people in the organization. Likewise we consider four interrelated influencers concerning curriculum development: The business environment where the student are employed, the engineering science forming the basis for the engineering disciplines to be included in the curriculum, the university environment which forms the framework for the educational programs, and the teachers and student involved in the programs. A fundamental feature of the model is that changes in one of the influencers will affect not only the curriculum but also the other influencers. Thus, for example, a development in the engineering science has an obvious impact on the subjects and courses to include in the curriculum but it also has an impact on the teachers and students and on the industry. These relations are there, no matter whether you make use of them or not. A conscious exploitation of the interdependencies can lead to a better curriculum development than a curriculum development based only on a subset of the influencers.

THE MODEL

The development model is shown in a generic form in fig. 1. Central to the model is the curriculum development. The four ellipses around the curriculum development illustrate the major influencers on the development and the arrows illustrate that all elements in the model depend on each other. The model as illustrated in fig. 1 is a generic model for the development of engineering curricula. With modest modifications it can also be applied to the development of curricula in other fields than engineering. In the following we apply the model to electrical engineering curricula using the CDIO syllabus as a concept for the program.

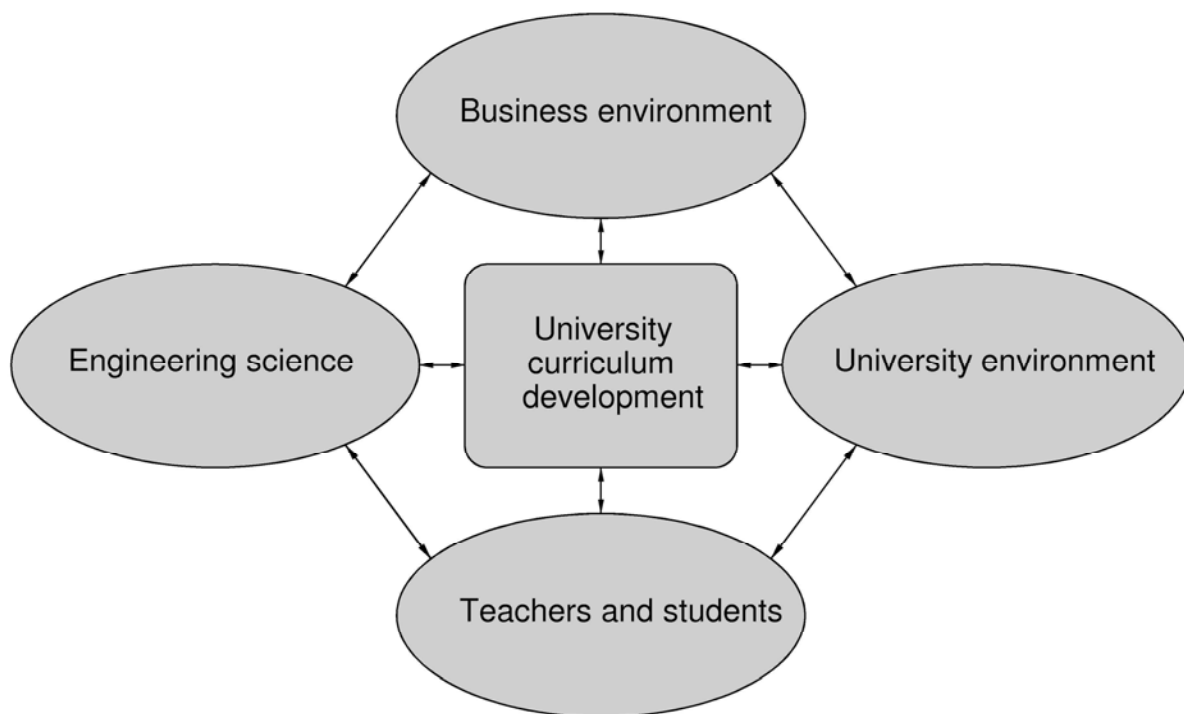


Figure 1. Major influencers on university curriculum development

Engineering Science

Science forms the basis for engineering. New discoveries and developments in physics, mathematics and computer science lead to engineering possibilities in electrical engineering. A well known method for predicting the engineering advances to expect in the foreseeable future is the development of roadmaps. Perhaps the most important roadmap for electronics is the International Technology Roadmap for Semiconductors [4,5]. This roadmap predicts the technology evolution during the coming 10 years and deals with many aspects of electrical and electronics engineering. Fundamental to the predictions is Moore's law [6] which states that the number of components on a chip doubles roughly every 24 months. This increase is obtained in different ways: smaller device geometries, larger chips, novel devices. More specifically, the roadmap deals with three different development tracks:

- *More Moore*. This track describes the direct extrapolation of existing CMOS technology using smaller device geometries. The impact of the scaling is that systems of giga-scale complexity measured in terms of number of components on a chip or in a package can be manufactured, using standard CMOS technologies. The scaling of device geometries is expected to reach a fundamental limit within the next decade.
- *More than Moore*: This track describes a development towards a technology combination between standard CMOS and different forms of microelectromechanical devices (MEMS), RF circuits, analog circuits, bio-devices, chemical devices, etc. The impact is that Microsystems/nanosystems become feasible through this technology fusion.
- *Beyond CMOS*: This track describes a development of new nanoelectronics devices. When the possibilities for device scaling in traditional CMOS become exhausted within the next decade, new devices are needed in order to continue the increase in number of components on a chip.

The three different tracks point towards different curricula: As discussed in [2], the 'More Moore' track points towards programs in computer engineering where the main challenge is how to utilize the increased complexity in larger systems. Of course, this track also requires development of technology engineering but the development of nanoscale CMOS processes takes place mostly in the Far East or in the USA and certainly not in Denmark.

The 'More than Moore' track points towards programs in electrical engineering where the skills of an electrical engineer can be utilized in the design of systems and product using different kinds of electronic devices.

The 'Beyond CMOS' track points towards programs in physics engineering since the main challenge in this track still is the development of novel physical device structures which can replace today's CMOS transistors. A considerable amount of further research and development is needed before new devices are established as the devices for future electronics engineering.

One of the consequences of the development described by Moore's law is that computing and signal processing electronics hardware has become much more powerful and that many development tasks have been changed from dedicated, specific hardware development to software development using generic hardware platforms. Thus, the role of engineering has changed and the balance between hardware development and software development is continually evolving. Likewise, the balance between analog and digital electronics is evolving with as many functions as possible being transferred to the digital domain where design automation is easier and where hardware platforms can be reused through the development of application specific software. Examples of these trends are seen for instance in the development of mobile phones and smart phones where the software content of the phone is what determines the functions of the phone. Also in fields such as audio amplifiers, digital signal processing and digital amplifiers have taken over from previous times' analog designs.

Business Environment

This part of the model deals with the job market that the engineering students are educated for. In an international perspective, the evolution of the engineering science has had a profound impact on the industrial job sector. Much of the electronic design has shifted from hardware to software and much of the hardware design has shifted from design with discrete components (transistors, resistors, small-scale IC's, etc) to integrated circuit design. The volume manufacturing of integrated circuit design is moving away from Europe and being concentrated in the Far East. The manufacturing facilities for modern integrated circuits are so costly that only a few, large multinational companies can afford to follow track on the development of new CMOS processes with even smaller dimensions [7]. Also, manufacturing and assembly of electronic systems based on printed circuit boards and various electronic subsystems are being outsourced to countries with a lower level of labour cost than in Europe.

From a Danish perspective, this means that the job market for electronics engineers has the following characteristic: There are no really large companies, there are no companies in mass consumer markets, there are no companies in semiconductors. Rather, the Danish electronics companies are small and medium-sized enterprises (SME's) in professional markets and OEM markets. They typically deal with niche products and in some niches Danish companies have a substantial part of the world market (hearing aids, wind mills, different types of biomedical equipment). Denmark has a large and innovative energy sector and also a large and innovative health sector. Also, Denmark has many start-up companies dealing with electronics. Examples are found in power electronics and in audio systems where companies emerge, based on engineering competences in the 'More than Moore' track, e.g. in developing new piezo-electric based power systems or new MEMS-based microphone systems. The engineers needed in start-up companies require competencies including conception of products, design and implementation and practical application and operation of products. Thus, the CDIO concept is very well suited for start-up companies.

University Environment

On a global scale, several important developments can be seen in the university structure. One is the adoption of the Bologna model for the university programs [8], i.e. three-years undergraduate (bachelor) programs, followed by graduate programs, in many countries consisting of two-years master programs and three-years PhD-programs. This leads to a harmonization of the university programs, paving the way to easier exchange of students and courses between universities. Another is an increasing internationalization with more programs at master level and PhD level being offered in English.

The vast development of new engineering fields and possibilities has the implication that few – if any – universities can offer programs in all fields of engineering. This leads to a specialization among universities. Some universities have very strong programs in e.g. electronics while others have their particular strengths in other fields, e.g. chemical engineering. Specialized programs such as arctic technology can only be found in few places. However, students are becoming more mobile and the development of a common structure for the educational programs facilitates student exchange between universities. Therefore it makes sense to establish alliances between universities with matching or complementary competences so that joint programs can be developed in fields not fully covered by a single university. This is an important step towards building educational networks.

In addition to the international trends described above, local policies, rules and regulations influence the development of educational programs. The Technical University of Denmark (DTU) offers Bachelor of Engineering programs (B.Eng.) based on a ministerial order from 2002 [9]. This order defines the B.Eng. programs as programs comprising 210 ECTS credits (corresponding to 3½ years) and with the aim of qualifying the students for professional engineering jobs. Also, DTU offers Bachelor of Science programs (B.Sc.) and Master of

Science programs (M.Sc.) based on another ministerial order [10]. The B.Sc. programs are primarily aimed at providing a basis for further studies in the M.Sc. programs and, thus, the B.Sc. programs differentiate themselves from the B.Eng. programs. Only the B.Sc. and M.Sc. programs follow the Bologna model. The policy of DTU dictates that the bachelor programs are taught in Danish, basically aiming only at Danish-speaking students, whereas the master programs are English, aiming at international students. Of course, this creates some limitations concerning the educational networks which can be implemented. Presently, the international dimension is much stronger in the B.Sc./M.Sc. program line. Another declared policy of DTU is that the CDIO syllabus is used for all of the B.Eng. programs but not necessarily for the B.Sc. and M.Sc. programs. A practical implication of this university policy is that the B. Eng. curriculum in electrical engineering is directly aimed at providing engineers for the professional Danish electronics industry with top-class abilities in design and development of electronic systems, whereas the B.Sc./M.Sc. curriculum in electrical engineering aims broader, also at an international job market and at jobs in research and development. Each of the programs is headed by a program coordinator who is also the driving force in the development of the curriculum within the general framework defined by the ministerial orders and the policy of the university.

Teachers and Students

Teachers and students play a decisive role in the developments of a curriculum. The curriculum has to be able to attract students with a relevant background from upper secondary school programs. Teachers with an interest in the subjects included in the curriculum have to be available. Also, teaching facilities, classrooms and laboratory workspace must be available.

In Denmark, the recruitment of students to engineering comes mostly from the STX program (Gymnasium) which has a focus on general education and on general study preparation and from the HTX program (higher technical examination program) which has an emphasis on subjects within the technics and natural sciences. Annually, about 25,000 students complete the STX or HTX program. From these, about 540 chose a B.Eng. program at DTU and from these, about 80 select the electrical engineering program which takes in students both in September and in January. This is an intake which is large enough to provide a good study environment and teamwork among the students while still being manageable for the laboratory workspace available.

A major influencer on the contents of the curriculum is the professional interest of the teachers. At DTU there is a common corps of teachers for all the educational programs, implying that teachers in all of the programs, including the B.Eng. programs, are active researchers. This gives a link to the engineering science and implies that most teachers have a strong interest in research. Many teachers also maintain strong links to industry, providing the necessary background for cooperation with industry about thesis work and trainee service.

DESIGN OF THE CURRICULUM IN ELECTRICAL ENGINEERING

One of the challenges in the curriculum design is to take into account each of the influencers in the model above in a systematic way. The model helps in structuring the process and in pointing out the relations between the influencers but it is necessary to acquire a sufficient amount of information about the influencers in order to take them into due consideration.

Several sources of information are available. Concerning the engineering science, an important source of information is the systematic overview of development trends given in roadmaps like the International Technology Roadmap for Semiconductors [4,5] but also the general knowledge about current and future research topics gathered from the active researchers at DTU is a valuable input to the curriculum development.

Concerning the business environment the CDIO Syllabus [1] suggests an involvement of focus groups including a group of industrial representatives (in addition to groups including faculty, current students and alumni). At DTU each department has an advisory board with representatives from industry and the contents of the B.Eng. curriculum in electrical engineering has been discussed with the advisory board of the Department of Electrical Engineering. Information about the business environment is also accessible from sources including the Danish Society of Engineers and professional organizations such as the Confederation of Danish Industry and DI ITEK (the Danish ICT and electronics federation for it, telecommunications, electronics and communication enterprises). A valuable source of information is also the direct contact to industry which many teachers have on a professional basis.

Concerning the university environment, the information needed for the curriculum development is available from internal sources (about university policies, etc) and from the public organizations defining the framework for the curricula, in particular the Ministry of Education and the Ministry of Science, Technology and Innovation.

Concerning students, teachers and teaching facilities, facts and figures are available from internal sources with numbers for student intake, faculty staff, workspace facilities, etc. and from external sources (Ministry of Education) concerning the students' background from their upper secondary education.

All of this information has to be gathered by the program coordinator and formulated into a proposal for a curriculum which is then discussed in a study planning committee involving teachers and students and in the formal bodies of the university (department study committee, inter departmental program committees) before being reviewed and finally approved by the Dean of Education.

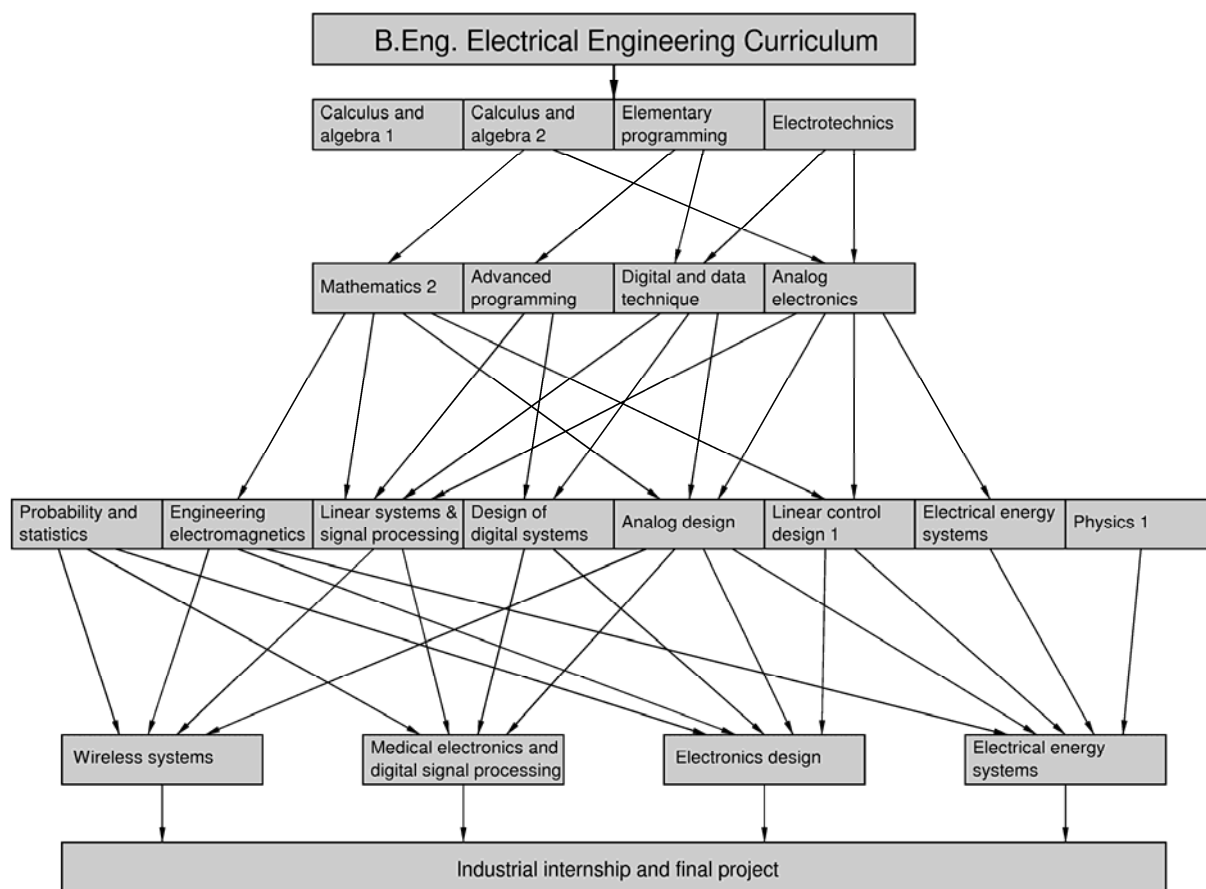


Figure 2. Bachelor of Engineering program for electrical engineering

The outcome of this process concerning the CDIO based B.Eng. curriculum in electrical engineering is shown in fig. 2. A detailed description of the curriculum and how it fits to the CDIO requirements is given in [11]. Here we will relate some features of the study plan to the model described above.

Technical knowledge: The technical knowledge included in the program is a combination of scientific knowledge and core engineering fundamentals in mathematics, physics and computer engineering (programming) and of engineering fundamentals and advanced topics in electrical engineering. The core engineering fundamentals are common to several B.Eng. programs. Thus, their content and definition is strongly related to the educational policy of DTU with departments in mathematics and physics being responsible for these courses, rather than the engineering departments. The engineering fundamentals and advanced topics in electrical engineering are defined by the engineering departments, primarily Department of Electrical Engineering. In the engineering fundamentals, emphasis is on analog and digital electronics, electromagnetics, signal processing and electrical energy systems. Approximately the same effort is devoted to analog and digital electronics. This may at first glance seem strange (in conflict with the general trend in engineering science) but it is a reflection of the teachers' interest, the kind of job functions (often in SME's working in the 'More than Moore' domain), and of the fact that another B.Eng. program is offered by DTU with an emphasis on computer engineering and digital systems. The other engineering fundamentals have been selected such that they support the advanced topics offered in wireless systems, medical electronics and electrical energy systems. These advanced topics have been selected because of a combination of a strong interest and background from the teachers and an industrial base in the Danish industry.

Personal and professional skills: When coming to personal and professional skills, the framework of the CDIO syllabus comes into play. DTU has developed a 'Handbook for CDIO in the B.Eng. programs at DTU' [12]. This handbook gives guidelines concerning how to formulate learning objectives for the courses in such a way that the professional skills are developed through a progression in the technical knowledge. Also, guidelines for the definition of projects are given in the handbook. This is an example of the influence of the university environment on the specific curriculum development, firstly through the adoption of the CDIO concept at DTU on the basis of international university trends, and secondly through the implementation guidelines described in the handbook. In order to combine this university influence with influence from industry, an investigation of industry attitude towards the skills defined in the CDIO syllabus was conducted before launching the CDIO based B.Eng. programs. The results of this investigation indicate an emphasis from industry on the professional skills [13]

Interpersonal skills: Also the interpersonal skills are treated in the CDIO handbook [12] and, thus, serve as an example of the strong influence of the university environment on the curriculum development. The impact of the other influencers in the model in fig. 1 is less pronounced, but it is a general trend in both engineering science and industry that results are increasingly achieved through teamwork requiring interpersonal skills, rather than through the work of individuals. This trend is also seen among the teachers where teams of teachers are assigned to parts of the educational program rather than individual teachers. The teamwork among the teachers also serves as a cultural structuring element in the educational program [11].

Conceiving and engineering skills: These skills are generic engineering skills (not specific electrical engineering skills) dealing with systems design and implementation. In the CDIO syllabus, a very strong emphasis is put on these skills (Conceive – Design – Implement – Operate) which is fully in line with the trend in electrical engineering science where systems are becoming more important for the electrical engineer than circuits, and it is also in line with the Danish business environment where systems, typically for the professional customer,

is a common product. Again, the university policy of DTU has dictated that the conceiving and engineering skills should be incorporated into the educational programs through the CDIO syllabus as described in the DTU CDIO handbook [12].

CONCLUSIONS AND RECOMMENDATIONS

A model describing four important influencers on curriculum development has been developed and described. The model operates with the following influencers: Engineering science, business environment, university environment, and teachers and students. The influencers are related in such a way that changes in one of the influencers also affect the others, so they cannot be treated independently. A deliberate exploitation of the relations between the influencers can lead to a better curriculum development than a curriculum development based only on a subset of the influencers. The model is used for the development of the CDIO based curriculum in electrical engineering at DTU. The fact that DTU has chosen the CDIO syllabus as the basis for the B.Eng. programs directly gives a very strong impact from the university environment on the curriculum development, but the CDIO syllabus already takes into account some of the stakeholders in the engineering programs, industrial representatives, the teachers, the students, and former students. In this way, the other influencers in the model are also incorporated into the curriculum development, not only directly but also indirectly through the CDIO syllabus.

The resulting B.Eng. program in electrical engineering is shown and it is concluded that this program has been developed taking both the CDIO syllabus and the characteristics of the Danish business environment and the characteristics of the DTU faculty into account.

The overall recommendation is that a conscious use of the model described in the present paper can structure and improve the curriculum development in a way leading to a well founded and well structured curriculum.

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Biographical Information

Erik Bruun received the M.Sc. degree and the Ph.D. degree in electrical engineering from the Technical University of Denmark (DTU) in 1974 and 1980, respectively. In 1980 he received the B.Com. degree (HD) from the Copenhagen School of Commerce (now Copenhagen Business School). In 2000 he also received the dr. techn. degree from DTU. Since 1989 he has been a Professor at the Department of Electrical Engineering, DTU. Erik Bruun is currently involved in research concerning analog integrated circuits and systems and he is involved in teaching of analog electronics at both undergraduate level and graduate level.

Claus Kjærgaard received the B.Eng. (hon.) in electronics engineering from the Danish Engineering Academy 1984. In 1984 he joined the Danish Engineering Academy, which is now part of DTU. He is currently an Associate Professor at the Department of Electrical Engineering, DTU. For many years his research was focused on reliability of repairable electronic systems. During the last 10 years his work has been focused on teaching and developing courses and study plans in the field of analog electronics and hybrid microelectronics and on research in these fields. In 2006 he received the reward as best teacher in the B.Eng. educational programs at DTU. Since 2005 he has been head of studies for the B.Eng. program in electronics and has been responsible for the implementation of CDIO in this program.

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A CDIO APPROACH TO CURRICULUM DESIGN OF FIVE ENGINEERING PROGRAMS AT UCSC

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ABSTRACT

This paper describes the process followed by the UCSC School of Engineering in order to redesign its five engineering programs using a CDIO-based approach. The redesigned programs were the Computer Science, Industrial Engineering, Civil Engineering, Logistics Engineering and Aquacultural Biotechnology Engineering programs. First, we present the motivations behind this work, namely, the desire to update the curricula so as to incorporate novel teaching and learning methodologies, and to improve our performance indicators. Next, we explain the UCSC ethos, its pedagogical model and the CDIO approach that together frame our curriculum design process. Then, the different stages of this process are presented and described at length. We then present several results from the Conceive and Design phases of the CDIO approach. These results also include reports from pilot Active Learning experiences and Service Learning experiences. Our curriculum design process started in 2008, and to date we have completed the Conceive and Design phases of the CDIO approach, with the Implementation phase starting this year. This has been a slow and laborious, but ultimately very rewarding, process. The main working team members had no previous experience with curriculum design, nor were they familiarized with currently engineering education trends. A Chilean MECESUP government grant allowed team members to visit leading innovative engineering schools, and also financed workshops for local faculty by well-known international experts. Our experiences to date and the growing involvement of early adopters and other faculty members show promise, and lead us to hope for a sea change in institutional mores by instilling the culture of continuous improvement in the educational process.

KEYWORDS

Curriculum design; CDIO syllabus, benchmark, mapping CDIO skills

INTRODUCTION

Over the last decades, there has been an increasing awareness that professionals coming out of engineering schools are not meeting all current industry needs. This observation is not related to the graduates' engineering knowledge but rather to certain lacking personal, interpersonal skills and attitudes. This issue has become common knowledge and has been

revealed in many studies conducted in several countries, all of them reaching the same conclusions.

Most engineering programs in Chile present, in varying degrees, one or more of the following problems: inflexible curricula overly constrained with excessive courses and requirements, courses overloaded with contents, lack of flexibility within programs and also across different programs and universities, and a lack of intermediate exit degrees. Additionally, the School of Engineering of the Universidad Católica de la Santísima Concepción (UCSC) has identified other problems such as serious deficiencies in first-year student skills, low student retention rates, high course failure rates, and excessively long effective program durations.

The UCSC School of Engineering is committed to improving its current offerings. After an extensive exploration process, they decided to redesign its five engineering (Computer Science, Industrial Engineering, Civil Engineering, Logistics Engineering and Aquacultural Biotechnology Engineering) programs using a CDIO-based approach.

Why a complete curriculum design and not just a specific innovation within the curriculum?

We believe that, by not having a complete curriculum based on a CDIO approach, any specific initiatives that are carried out within the curriculum can sometimes get diluted during the student's learning process. This can be illustrated by picturing a very motivated student doing hands-on learning and who, after the bell rings, must attend his next class which is taught in a traditional way. During the first hour we're having him think for himself in order to learn, and in the next hour, we expect him to go back to a passive learning state.

Our first learning experience was realizing that the curriculum design process was by itself also an engineering process. Therefore, it can also be thought of as having all 4 parts of the CDIO approach (Conceive-Design-Implement-Operate). This work considers the conception and design of the new curriculum, as the implementation stage started March 2011.

As stated before, this has been a learning experience, and through this paper we will describe the whole process, as well as our main conclusions and recommendations.

FRAMEWORK

The world has changed, it always has and it will continue to do so. This is a fact. Education hasn't always been able to keep up with this continuous transition, and engineering education is not the exception. Fortunately, this issue is already being addressed within many engineering schools worldwide, but they're faced with the difficulty that most engineering professors are experts in their fields, but not necessarily in education. Therefore, this new engineering education movement has taken them out of their comfort zone and into a new and unexplored field.

Refocusing education away from the traditional passive approach towards one more centered on the students and their skills and capabilities and less on knowledge, is a world movement that affects the entire education process (K-12 and higher education). There are several theories, movements, approaches, declarations and agreements among stakeholders and even countries (Tuning Latin America, the Declaration of Bologna, the CDIO initiative, among many others). In spite of the differences among them, they all focus on the same fundamentals: more skills and less knowledge, flexibility, a focus on learning outcomes, integral development, etc.

The UCSC Institutional Pedagogical Model

The Universidad Católica de la Santísima Concepción is a private catholic university which brands its students with its hallmark through its institutional pedagogical model. The UCSC pedagogical model is a human-centered model based on four cornerstones, as shown in Figure 1. All new study plans and curricula must conform to this pedagogical model. This model was established in 2009, after our curriculum design process had already started. We now present the pedagogical model and indicate its correspondence to the CDIO standards, as presented in [2].

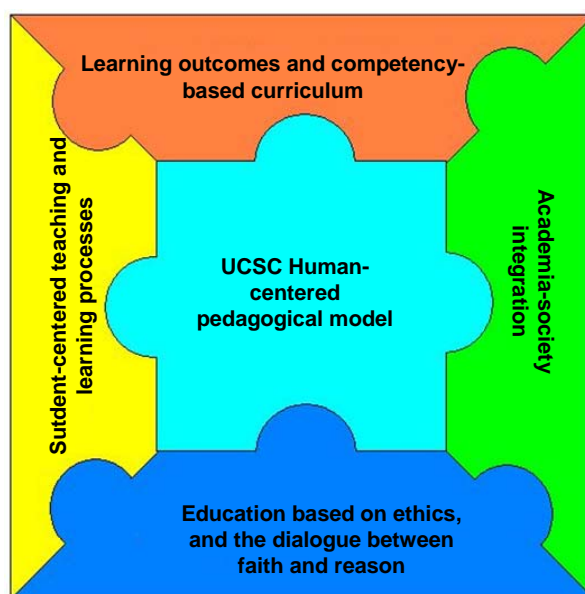


Figure 1: UCSC institutional pedagogical model

The first cornerstone is a learning-outcomes and competency-based curriculum, corresponding to CDIO Standards 2 and 3. It comprises recognizable and measurable competency-based program outcomes, intermediate program exits, flexible career paths, and evaluation by learning outcomes and competencies (CDIO Standard 11).

The second cornerstone is a student-centered teaching and learning process (CDIO Standard 8). It comprises faculty pedagogical and disciplinary development (CDIO Standards 9 and 10), progressive learning autorregulation, and teaching and learning resources availability (CDIO Standard 6)

The third cornerstone is education based on ethics, and the dialogue between faith and reason. It comprises recognizing truth as the convergence point between faith and reason, ethics education, and anthropological formation across the curriculum.

The last cornerstone is the integration of academia and society. It comprises generating meaningful links between student and society (CDIO Standards 4, 5 and 7), and also ensuring program outcome relevance to industry and society.

The CDIO Approach

We embraced the CDIO initiative as our guiding framework because it proposes a student-centered curriculum, created for and by engineers in collaboration with education experts, that captures the essence of engineering itself, by stressing the fundamental domains of Conceiving, Designing, Implementing and Operating real-world systems and products. It is

not only a methodological approach but also a network of associated institutions that collaborate by sharing their know-how and experiences in pedagogical innovations, to help improve engineering education. It has been applied successfully in many engineering program. Moreover, many of its available resources are written in a way that any engineering professor can understand. This is of great importance because of the fact that any curriculum change process has to be carried out within the engineering schools and by the faculty members themselves.

The CDIO approach addresses two main questions:

“What is the full set of knowledge, skills, and attitudes that engineering students should possess as they leave the university, and at what level of proficiency?”

“How can we do better ensuring that students learn these skills?”

To these two questions we add a third one: “How do we do this and where do we start?”

To answer the first question, the CDIO Initiative has developed a detailed and comprehensive list of knowledge, skills and attitudes that students should learn and be able to do at the end of their engineering studies. These learning outcomes are codified in the CDIO Syllabus. This syllabus can be successfully compared with other accreditation criteria, such as those used by Chilean higher education accreditation agencies. Moreover, the CDIO syllabus contains more levels of detail. Therefore, when facing the task of defining learning outcomes for an engineering program, it is wise to use the CDIO syllabus and to validate it with the local stakeholders, instead of starting from scratch.

The answers to the second question are contained within the 12 CDIO Standards, which could also be seen as the backbone of any engineering curriculum. They address issues going from the basic principle that engineers conceive-design-implement-operate products and processes, up to topics such as curriculum development, design-implement experiences and workspaces, methods of teaching and learning, assessment and evaluation. In regard to curriculum development, these standards state the need for a curriculum that integrates personal, interpersonal and engineering skills.

Among the teaching and learning methods, active learning is of particular interest to us. It changes the focus from the teacher towards the students, engaging them directly in their learning process, by the means of having them think and do experiential activities (by themselves or in groups), that will help them learn in a more active and effective way, as opposed to the traditional passive state of just receiving information. Therefore, active learning is a constructivist way of learning new knowledge, but not only that, since as a “side effect” or “spin off effect”, it also helps develop other crucial skills and attitudes that are required in an engineer, such as learning to learn, teamwork and interpersonal skills and attitudes. There are many active learning methodologies and techniques that can be suitable for engineering programs but we will emphasize problem-based learning, inquiry-based learning, project-based learning and service-learning.

The third question will be answered throughout this paper, mainly by the exposition of our curriculum design process, for which we adopted the CDIO standards, as well as other curriculum design principles and techniques obtained from literature and experts.

THE CURRICULUM DESIGN PROCESS

The main process used for conceiving and designing the new engineering programs is summarized in Figure 2.

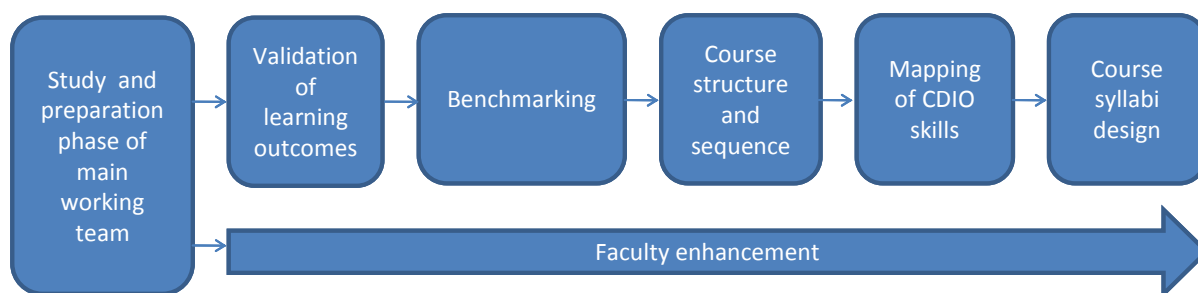


Figure 2. Curriculum design process

The organization used to carry out this process consisted of a main working team composed of six faculty members, two from the Computer Science program, and one from each one of the other four programs. This team was the driving force of the process, and each member was charged with acting as the nexus with faculty of their own department.

Study phase and preparation of main working team

The initial study and preparation phase was carried out by the main working team, which had the responsibility of conceiving the process and setting out a road map. This first stage, and the team itself, were crucial and became the foundation of the whole process.

The initial steps taken were to diagnose the current situation according to the latest developments in engineering education locally and throughout the world, and also to take an inside look of the situation at UCSC and the local industry. The results of this diagnosis weren't any different from those obtained by other studies conducted in Chile and worldwide, whose main conclusions were already stated at the beginning of this paper. The only major difference detected was regarding the pre-existing skill set of first-year engineering students at UCSC. Five tests were applied to first-year engineering students, in order to determine their entry conditions regarding their social skills, self-concept, their skills using information and communication technologies, mathematic skills and basic language skills. Each test is briefly described below:

Social skills: This test evaluates skills in terms of interpersonal relationships, assessing their behavior in different situations.

Self-concept: This test evaluates the concept that each student has of him or herself, considering five dimensions: social, academic/professional, emotional, family and physical.

Information and communication technologies skills: This test assesses the students' skills at using a computer. Some self-concept test results are presented further ahead.

Mathematics: This test evaluates basic algebra and calculus skills to establish a baseline.

Basic language skills: This test assesses reading comprehension and production of a text of no more than 200 words on a given topic, assessing the organization of ideas, writing, spelling and quality of writing.

An important outcome of this phase was deciding upon a specific model or approach to be applied to the curriculum design process. To this purpose, visiting foreign educational institutions and seeing other innovative experiences first-hand was truly helpful and a real eye-opening experience. It was during this exploration phase that the CDIO approach was selected as our main model.

Another important input considered in this phase was the experience of two other Chilean engineering schools, those of the Universidad de Chile and the Pontificia Universidad Católica de Chile. They used the CDIO syllabus for their curriculum renovation process, and validated it with local stakeholders.

Another fundamental decision taken during this phase was to rely on expert assistance. In spite of all available written and online resources, it is fundamental to have the help of someone that can lead you through the process, especially if the main working team doesn't have any previous curriculum design experience. In our experience, the expert selection is a crucial decision, as that person must have experience working with both engineering curriculums as well as with engineering faculty. In our case, we were fortunate enough to work with Prof. Doris Brodeur from M.I.T., who is not only part of the CDIO initiative, but also has a vast experience in curriculum.

This curriculum design process was financed through a MECESUP grant (USC06010), which are government funds aimed at improving the quality of higher education. This specific project had as its goal the formulation of a plan for a curriculum reform process of the engineering programs at UCSC, emphasizing competency development, curricular flexibility and continuous education.

Faculty Enhancement

Faculty enhancement is a long and laborious process, requiring extensive support and commitment from the host institutions, and much dedication and personal effort from the team participants. To this purpose, the international CDIO network has proved itself priceless, as it has allowed us to participate in international workshops, share experiences and novel teaching ideas with enthusiastic engineering educators from all over the world.

Starting in mid 2006, the School of Engineering created its main working team, which was tasked with leading the effort to renovate the curriculum of 5 programs, with the stated goal of applying for the aforementioned government MECESUP grants. To this end, team members attended several national-level workshops, conferences and seminars on educational reforms in higher education. In particular, the team got familiarized with the Tuning Latin America project, the Declaration of Bologna, and other educational initiatives.

After applying for and receiving a MECESUP grant for the curriculum renovation at the School of Engineering, the main working team focused specifically on curricular renovation experiences in Engineering Education. Thus, they got acquainted with the CDIO Initiative through the experience of the Universidad Católica de Chile and the Universidad de Chile. This framework appeared to be uniquely suitable for the process at hand.

Faculty enhancement was performed as follows: main working team members visited several international institutions that have implemented innovations in engineering education to study them in situ. These visits led in turn to contacts with experts in several areas, some of which were invited to give workshops at UCSC and help guide the curriculum design process. At the same time, team members also led workshops for other faculty members, so as to motivate and engage them in the curriculum reform.

Visits

In 2008, team members visited the Franklin W. Olin College of Engineering and got in touch with Doris Brodeur. Also, they attended the International and Regional CDIO Meeting at Arizona, which in turn led to contacts with several other CDIO members and LASPAU. In particular, we got in touch about other Latin-American engineering schools that are implementing curriculum reform projects using the CDIO approach, such as UNITEC – Honduras and the Universidad Javeriana, in Colombia. This was a very productive and motivational meeting, which led us to attend the 2009 CDIO Region of the Americas Workshop at Boulder, Colorado. At the same time, LASPAU was instrumental in arranging visits to Harvard University, where we learnt about effective class management and how

their teaching and learning centers support faculty improvement and innovation; to the Massachusetts Institute of Technology, where we visited the Dept. of Aeronautics and Astronautics to learn about their experiences with the CDIO Initiative, and also heard about M.I.T.'s Writing across the Curriculum program; to Brown University, where we visited the Sheridan Center for Teaching and Learning; and finally to Olin College of Engineering, where team members got knowledge of their hands-on learning and project-based programs, with their emphasis on social responsibility and innovation.

In October of 2009, team members visited Sherbrooke University, Canada to learn about competence-based curricula, project-based learning and co-operative education models. Later, at the École Polytechnique de Montréal they became familiarized with the curricular reform process based on the CDIO approach followed at the Mechanical Engineering Dept., and visited the Bureau D'Appui Pédagogique to learn about the extensive pedagogical support available to both full-time and part-time faculty at this center. At the Massachusetts Institute of Technology, team members visited the Teaching and Learning Laboratory and heard about their experiences with the application of active-learning methodologies to their first-year physics courses, and also how their engineering leadership programs are preparing future leaders in innovation and invention. The team's visit to Northeastern University was very insightful, thanks to their vast experience with co-operative learning, service learning and project-based learning, as well as their relationship model with industry and other organizations. At Bentley University and at the Massachusetts College of Pharmacy and Health Sciences, team members learnt even more about service learning and how to build successful relationships with community organizations. Finally, visiting the Worcester Polytechnic Institute was a great introduction to project-based learning and their experiences with projects that take students abroad.

In 2010 team members visited the University of New England in Armidale, Australia, to learn about the design and development of measures and instruments for curriculum assessment.

Workshops

In mid-2009, a workshop on how to benchmark core engineering fundamentals using a specialized tool based on an Excel spreadsheet was held and attended by all full-time participating faculty members at UCSC.

Doris Brodeur visited UCSC in August of 2009 for two weeks, during which she led a workshop on designing an Outcomes-Based Curriculum, and a workshop on The Course Syllabus: Planning Student-Centered Courses. These workshops were attended by faculty of all engineering programs, many of whom became early-adopters of the proposed reforms.

Susan Vernon-Gerstenfeld from the Worcester Polytechnic Institute visited UCSC in October of 2010, where she led a workshop on Applying Project-Based Learning to Undergraduate Courses, and a workshop on Applying Project-Based Learning to a First-Year Undergraduate Course. These workshops were open to all engineering faculty.

Also, in 2010, the UCSC created the Centro de Innovación y Desarrollo Docente (CIDD), a teaching and learning center to assist full-time and part-time faculty in improving their teaching skills and to support education innovations. To this purpose, they certify faculty members in: learning-outcomes based course design, active-learning methodologies, learning-outcomes assessment, and using information technology tools in higher education.

With the creation of CIDD, the School of Engineering handed over the responsibility of assisting faculty members who wish to improve their teaching skills and incorporate novel educational ideas to CIDD. At the same time, the CIDD has given first priority to those university programs that are implementing curriculum reforms.

This is only the first step. Faculty enhancement is a slow, deliberate process that requires resources, time, effort and dedication from the faculty, but we are confident that the creation of the center marks a milestone in the road to continuous teaching skills improvement at UCSC.

Validation of Learning Outcomes

Learning outcomes validation was done using the learning outcomes and skills list proposed by Universidad de Chile and Pontificia Universidad Católica de Chile in [1], which is an already validated version of the original CDIO syllabus, slightly modified for the Chilean context. The validation process was done through surveys, interviews and focus groups with the main stakeholders (students, alumni, employers and faculty).

The same survey designed by [1] was used to validate learning outcomes, as to allow future comparisons. Faculty, employers and alumni of each of the five engineering programs answered the survey via a web application. Survey subjects evaluated the importance of each skill using the scale shown in Table 1.

Table 1. Evaluation Scale

Level		
0		<i>It's not necessary to have obtained any proficiency level of the skill.</i>
1	To know	Have been exposed to the skill
2	Participate and Contribute	Know and discriminate situations or activities that require the skill
3	Understand and Explain	The capacity of being able to pass the skill to others and train them,
4	Apply	The capacity of being able to put in practice or implement the knowledge or skill in the right situation
5	Innovate	The capacity to manage and apply perfectly the skill in order to be able to innovate, lead and create new knowledge in the field

After the surveys, interviews and focus groups were carried out in the cities of Concepción, Temuco and Santiago, to faculty, employers and alumni. Some key headhunters were also interviewed.

Benchmarking

The benchmarking stage had 2 main parts. The first part involved benchmarking the CDIO skills (levels 2, 3 and 4 of the syllabus), and teaching methods and the second part benchmarked core engineering fundamentals (level 1 of the syllabus). Normally, this last part is not necessary for US or Canadian engineering programs. However, courses in Chilean engineering programs are usually overloaded with technical knowledge. Thus, in our case benchmarking allows us to identify the “fat” in our courses.

When benchmarking the CDIO skills, faculty had to determine which specific skills, up to the second level of detail of the CDIO syllabus, were addressed in their course. Also, they had to specify the manner of addressing each one of them as one of the following:

Introduce: The skill is only mentioned and is not assessed.

Teach: Significant time is spent on teaching the skill (theory, practice and/or application), and it is assessed.

Use: The skill is used, that is, the student is expected to have learned this skill previously.

A slightly different approach was used to benchmark the core engineering fundamentals. For every specific course content, faculty had to specify the level at which it was taught: theory, practice or application; what specific technical knowledge did a student need to know, and the time required inside and outside the classroom.

To this purpose, we designed a tool using a Microsoft Excel spreadsheet, which turned out to be very useful for the faculty members that were consulted, as it didn't require any assistance, and also made data processing much easier.

Benchmark spreadsheet design

Two different spreadsheets were designed for the benchmarking process. For the first part, skills up to the second level of the CDIO syllabus (x.y), were listed in the spreadsheet. The third level of detail (x.y.z) was displayed afterwards within a frame, as shown in Figure 3.

3 DESTREZAS INTERPERSONALES: TRABAJO EN EQUIPO Y COMUNICACIÓN		Nivel de Logro
Describir el papel de mentores y asesores		
3.1.5 Formación de equipos técnicos		
Describir el trabajo en diferentes tipos de equipos:(5b) Equipos con disciplinas mixtas (incluyendo no de ingeniería) Equipos pequeños comparados con equipos grandes Distancia, distribuidos y entornos electrónicos Demostrar colaboración técnica con los miembros del equipo		Inserte una I si sólo introduce el contenido una E si enseña el contenido y una U si sólo lo usa.
3.2 COMUNICACIÓN EFECTIVA		
3.2.1 Estrategia de comunicación		
Analizar la situación de comunicación Escoger objetivos de comunicaciones Analizar las necesidades y la composición del público Analizar el contexto de la comunicación Escoger una estrategia de comunicación Escoger la combinación apropiada de medios Escoger un estilo de comunicación (proponer, repasar, colaborar, documentar, enseñar) Seleccionar el contexto y la organización		

Figure 3: Personal, interpersonal and engineering skills template

When filling out this template, each faculty simply had to type in the yellow square one of the 3 options for addressing a specific skill: **I**: introduce; **T**: teach; **U**: use. If the skill was not addressed, they could simply leave it blank. The spreadsheet came with clear instructions, definitions and an example of how to fill out the template.

The spreadsheet design for the second part of the benchmarking process was slightly different. In this case, all courses were listed in the spreadsheet, along with their contents. Each course and content had a specific code, as shown in Figure 4.

Figure 4 shows the technical knowledge template for General Chemistry (Química General). The course code is 1.1.3, and it includes 11 contents or technical knowledge skills (codes 1.1.3.1 to 1.1.3.11). When filling out the template, professors fill out the columns on the right hand, which consider three aspects that were being benchmarked:

How that specific content was being taught (Theory, practice or by application).

Number of hours that a student should dedicate to the content (within and outside of the classroom). Faculty must also indicate whether the amount of hours considered were enough.

Which specific content (or technical knowledge skill) should the student already know in order to learn the one specified in the course being benchmarked, and at what level (theory, practice or application). Codes for other contents could be found easily within the spreadsheet.

IDENTIFICACIÓN GENERAL CURSO				Enseña		Horas semestrales			contenido 1 se necesita que se enseñe			
Carrera:				se enseña a nivel		no			¿Es suficiente?			
Código:						presenciales: presenciales: (S/si/N/no)			código			
Asignatura:												
Nombre:												
Asignatura:												
1	CONOCIMIENTO TÉCNICO Y RAZONAMIENTO			T	P	A				T	P	A
1.1	CONOCIMIENTO DE CIENCIAS BÁSICAS											
		1.1.2.3	Limite de funciones reales.									
		1.1.2.4	Continuidad.									
		1.1.2.5	La derivada									
		1.1.2.6	Aplicaciones de la Derivada									
		1.1.2.7	\mathbb{R}^2 y el plano real cartesiano.									
	1.1.3	QUIMICA GENERAL										
		1.1.3.1	Estructura atómica y clasificación periódica									
		1.1.3.2	Enlaces químicos									
		1.1.3.3	Nomenclatura básica									
		1.1.3.4	Leyes gravimétricas									
		1.1.3.5	Ecuación química									
		1.1.3.6	Estado gaseoso									
		1.1.3.7	Termoquímica									
		1.1.3.8	Mezclas									
		1.1.3.9	Cinética y equilibrio químico									
		1.1.3.10	Equilibrio iónico									
		1.1.3.11	Oxido reducción y electroquímica									
	1.1.4	ALGEBRA II										
		1.1.4.1	Vectores en \mathbb{R}^2 y \mathbb{R}^3									

Figure 4. Technical knowledge template

This information was processed in order to build a matrix that would allow different analyses. Hence, it was possible to establish which contents were required by other courses, helped us identify redundant content throughout the course programs, as well as establish relationships between the courses.

Course structure and sequence

The structuring and sequencing of the courses was carried out in different ways by each of the different engineering programs. However, they all considered as their input the output of the benchmarking process, which allowed them to rank all topics in order of importance.

The main working team developed a series of recommendations to guide the course structure and sequence, such as the number of courses per semester, number of service-learning hours, internship requirements, etc. As mentioned before, the UCSC's own curricular framework and pedagogical model set constraints on course structure and sequence. The desire to meet Chilean national accreditation board requirements and suggestions also put pressure on this stage. In some cases, such as the Computer Science program, the Association for Computing Machinery's curricular proposals were taken into account.

There was at least one member of each engineering program in the main working team, who was tasked with organizing a curriculum committee for course structure and sequence. This committee included a representative sample of all the program's specialization areas. The committee's job was to reorganize the existing course grids to eliminate unnecessary course requirements, elide redundant contents, reduce and streamline critical course paths, among other tasks.

These new curricula incorporate significant changes in the first-year introductory courses for all five engineering programs undergoing curriculum reform. Traditionally, these courses met for one or two hours a week, which was clearly not enough time for students to become fully

acquainted and motivated with their chosen professions. Our new curriculum design expands these courses to eight hours a week, so as to properly introduce students to their chosen fields of study, and also to familiarize them with the role of the engineer in today's society. Additionally, they must team up to plan and manage a simple project so as to exercise the CDIO basic competences (conceive-design-implement-operate). This course modification has been inspired by the University of Sherbrooke's first-year civil engineering courses [3]. These new courses also incorporate spanish-language teachers tasked with improving students' oral and written communication skills, specifically in technical reports, essays and oral presentations. Other communication skills courses were removed from the course grid and their learning outcomes are incorporated across the curriculum in a similar manner. These ideas, which are based upon the Writing across the Curricula program at MIT [4], present new challenges and opportunities for multidisciplinary and synergistic relationships between the schools of Engineering and Education.

At the same time, the UCSC has recently created the Centro de Acompañamiento del Estudiante (CEADE), a pedagogical center aimed at supporting the development of entering students' entry-level skills. This center has led workshops on improving study skills, autonomous learning and network building, which are held during the first five weeks of the introductory engineering courses.

Mapping

The activities previously mentioned lead to the mapping of the CDIO skills in the curriculum, which is one of the main cores of a CDIO-based curriculum. By mapping the CDIO skills within the curriculum we are taking responsibility for each one of them and making certain that students are exposed to a coherent curriculum. In other words, an integrated curriculum incorporates the personal, interpersonal and technical skills within the disciplinary courses, which traditionally address just disciplinary issues.

To this end, the curriculum committee for each program met during programmed working sessions with the grid of courses at hand. This committee was tasked with mapping each of the CDIO skills to one or more courses, in terms of being introducing, teaching or using the particular skill. For this task to be successful, constructive discussion is crucial and must be encouraged. Care must be taken to balance skills coverage across the courses. Also, it must be ensured that no skill is taught before it is introduced, nor used before it is taught. It is important to point out that the acquisition of any specific skill is a process that requires time, effort and training, so it's not something that you simply learn in a course. Therefore, each one of these skills should be taught in more than one course, and in each case the level of proficiency expected should differ.

Finally, it was also necessary to assert those particular skills that comprise UCSC's hallmark and make sure that they are included across the board.

Course Syllabi

Traditionally, our course programs have been written following a contents-based approach. An active learning approach requires course programs to be restated in terms of learning outcomes, and the syllabi helps ensure that students accomplish these learning outcomes. Initial work was done thanks to Prof. Doris Brodeur's workshops but later the CIDD took over the task of training faculty to use new institutional templates for course program and syllabi design. Additionally, the CIDD offers mandatory workshop for first-year engineering faculty on these subjects. These workshops will be soon extended to the rest of the faculty.

RESULTS

The work presented in this paper is the description of a Conceive-and-Design process, therefore, there are still no implementation results to report. Nevertheless, some of the activities carried out through the process generated interesting results and data that are presented below.

Self-Concept Test Results

As was previously stated, we applied five tests to first-year engineering students, in order to determine their entry conditions regarding certain skills. In this section we will give some results regarding the application of the self-concept test.

For this evaluation, we used the test presented in García y Musitu, which evaluates 5 basic dimensions: academic, social, emotional, family and physical [5].

From the results, it can be concluded that women had a higher self-concept in the academic, emotional and family dimensions, and a lower self-concept in the physical and social dimensions, when compared to men. There are no significant differences in the self-concept dimensions across engineering programs.

Validation of Learning Outcomes

As previously explained, learning outcomes validation was done through surveys, interviews and focus groups with the main stakeholders (students, alumni, employers and faculty). In the following figures, we present some of the main results obtained from the surveys for the Industrial Engineering program. Figure 5 shows the personal and professional skills evaluations made by the stakeholders, while figure 6 shows the interpersonal skills evaluations. Figure 7 shows the engineering skills evaluations made by the stakeholders, while figure 8 shows the technical knowledge skills evaluations.

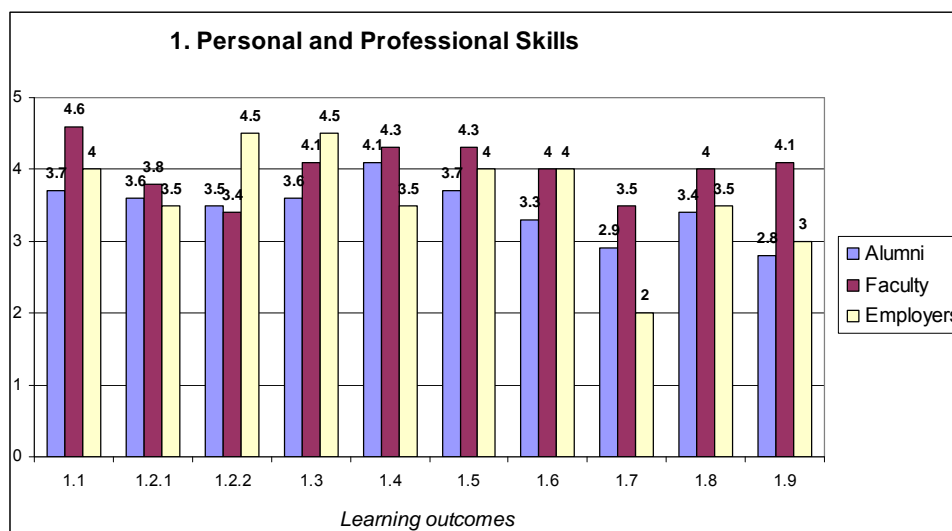


Figure 5: Personal and professional skills evaluation

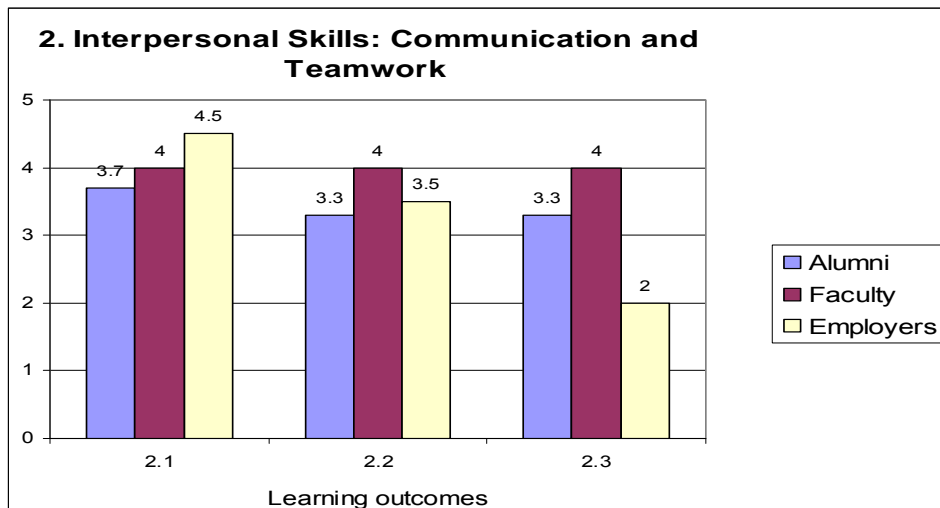


Figure 6: Interpersonal skills evaluation

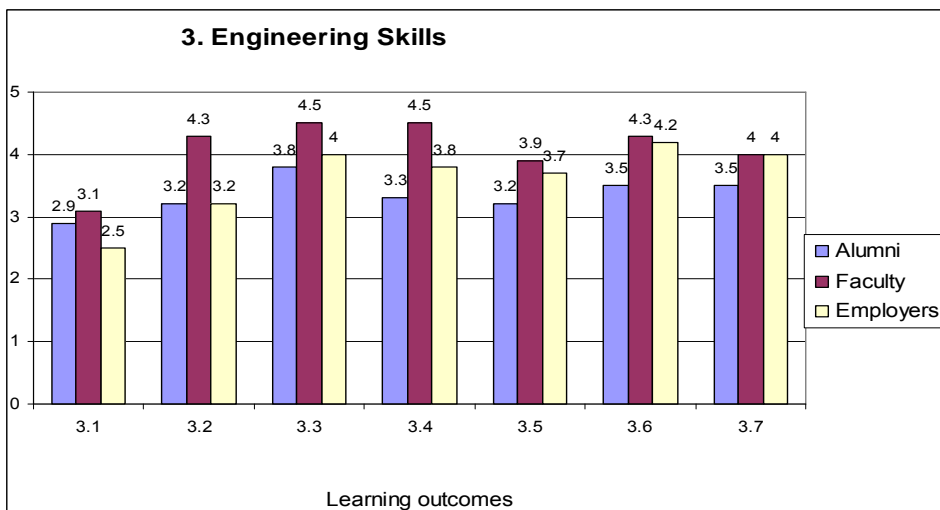


Figure 7: Engineering skills evaluation

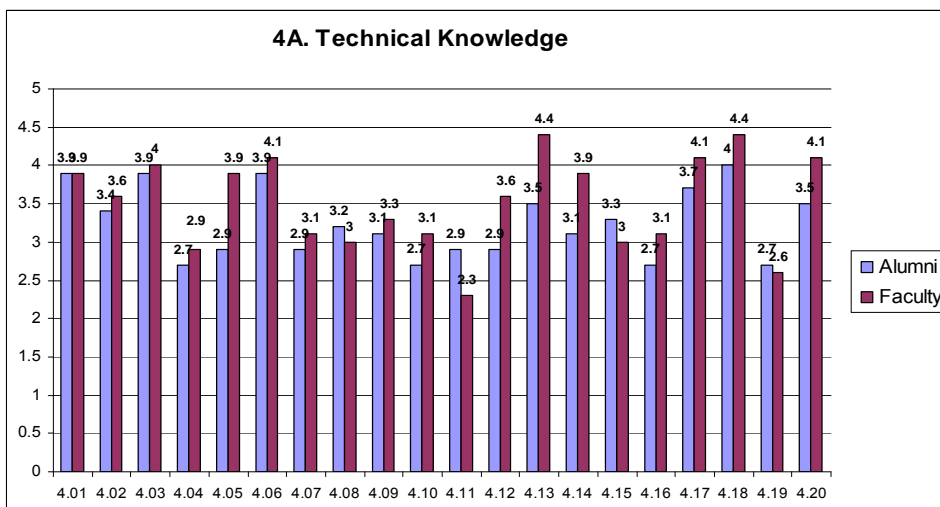


Figure 8: Technical knowledge skills evaluation

From analysing the data, we observed a strong positive correlation among the answers given by the different stakeholders and also between the different engineering programs. The data shows that faculty consistently overestimates the importance of technical knowledge, when compared to the other stakeholders.

The importance of alumni opinion can be seen in that it has the most statistical significance, as their answers have the highest correlation with the final results of the validation process. Also, of all stakeholders, alumni are usually those more willing to participate in these activities.

Benchmark results

The technical knowledge benchmark yielded several useful insights: many courses had topics that are not required knowledge for any other course in the grid. We also encountered courses that do not add to the learning outcomes program. Finally, the benchmark helped uncover redundancies where some topics were covered in more than one course

The personal, professional and engineering skills (PPE) benchmark helped us see that, while some courses address a large amount of PPE skills, others don't address any PPE skills. Many PPE skills are used in more than one course, but are not specifically taught in any courses. In fact, PPE skills are concentrated in just a few courses of the grid.

Innovative Pilot Experiences

Service Learning in Industrial Engineering

During the second semester of 2010, the Industrial Engineering program created a new elective course for seniors called "intervention in disadvantaged areas". In this occasion, the project was oriented toward helping neighbouring fishing villages which were damaged in the 2010 earthquake. As such, this course was also open to Marine Biology students. These students surveyed the marine resources management area to assess its post-tsunami status. At the same time, the Industrial Engineering students formulated and evaluated development projects to help these tsunami-ravaged fishing villages. Students worked with community leaders, fishermen, and family businesses to empower them to submit these projects to government grants at the regional and national levels. This work represented a significant savings for the community. Students showed great commitment and motivation, and all of them appreciated the opportunity to work in multidisciplinary teams on real-world problems in a socially responsible manner.

Problem-Based Learning in Aquacultural Engineering

The Aquacultural Engineering program incorporated problem-based learning in four courses. Students had to work autonomously, research relevant literature, design cultivation systems and periodically present their work. During these semester-long courses, students developed personal and professional skills such as responsibility, leadership, teamwork, critical thinking, creativity and resourcefulness. Students reported being highly motivated with these courses, many of them going beyond course requirements in their research projects. In some cases, their coursework led them to present their work in national-level conferences, with excellent results.

CONCLUSIONS AND DISCUSSION

Simultaneously re-designing five engineering curriculums has been an overly ambitious, work-intensive, slow and ultimately very rewarding collaborative group effort. We have

currently finished the course syllabi design stage for all first-year courses. We are now working on course syllabi for the rest of the curriculum, which, for some courses, is now an interdisciplinary effort, as they require input from several faculty members.

Embracing the CDIO initiative was crucial in our curriculum design process, since it's a framework designed for engineering programs. Access to the CDIO network of associated institutions, as well as to the many resources available on the CDIO website, has been of paramount importance to our efforts, as they have shown us tried-and-true educational techniques and approaches and also how to adapt them to our current reality.

Curriculum design has at times been a tedious and slow process, full of challenges and obstacles, that has extended itself beyond the original frame time. At the same time, it has been a unique team effort, which has brought together engineering faculty from different areas without any previous experience in curriculum reform. In spite of this, they were able to get out of their comfort zone and into a new discipline in which they ended up becoming the early adopters among their peers.

It is worth mentioning that, concurrently with our curriculum reform efforts, the university defined its pedagogical model and curricular framework for all its programs, and created a teaching and learning center as well as a student support center. This university initiative obviously aids the educational process, but because of the moment at which they were created, it sometimes resulted in lack of coordination between our efforts and duplicity of work.

Faculty enhancement is without any doubt a crucial stage in this process, not only during the conceive and design phases, but also, and maybe even more importantly, during the implementation and operation phases. It is fundamental to instill within the institution the culture of continuous improvement. Faculty are not always willing to commit to these changes, therefore a clear institutional vision and the proper incentives from the authorities are needed.

The active learning pilot experiences proved to be a very effective way of achieving the technical learning outcomes, as well as the so-called soft skills heretofore found lacking in previous students. Also, they were shown to highly motivate students as they engaged them in their own learning process. Introducing real engineering problems and experiences in the classroom helps students understand the fundamentals and see the theory into practice.

In retrospect, even though the curriculum design process described presents many difficulties and challenges, the application of the CDIO approach has proven to be effective, synergistic and also a great hands-on learning experience

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Biographical Information

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CDIO AS THE EDUCATIONAL AND CULTURAL STRUCTURING ELEMENT IN THE DTU B.ENG. IN ELECTRONICS PROGRAMME

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ABSTRACT

The aim of this paper is to describe how a CDIO based four semester study can be documented in such a way, that a homogeneous quality can be maintained over time. One purpose is to help new teachers to fully understand their role and obligations, not only in their particular course, but also as a part of the complex CDIO based education. The case used is the B.Eng. study in Electronics at the Technical University of Denmark (DTU)

Implementing CDIO calls for many changes in the way that we build and document an program, having implemented CDIO at the B.Eng. program in electronics, it has been found that the normal public and internal course documentation platforms are insufficient to keep the large amount of information needed to describe the program as a whole, and the large amount of interaction between the individual courses, a master document describing the program has been developed to cover the first 4 semesters in the program, this paper is meant as an inspiration to others that might find this method beneficial.

In todays modern and constantly changing society it must be expected that staff is constantly moving in and out between different research projects, while at the same time teaching courses at levels ranging from very advanced topics to introductory courses.

In most cases a course will be given by the same teacher every semester, but for some courses (often the introductory courses) teachers change frequently.

In this dynamic system the master document proposed helps in conveying crucial information from prior to new teachers, that otherwise could be lost in the teacher exchange process.

KEYWORDS

CDIO-based curriculum, Master document, Quality assurance, Learning objectives, Design-build projects, cross disciplinary projects, Soft skills implementation, Curriculum planning

INTRODUCTION

Today two different lines of engineering programmes exist in Denmark.

- 1- The Bachelor of Engineering programs (B.Eng.) and
- 2- The Bologna model based Bachelor of Science + Master of Science (BSc + MSc)

The Bachelor of Engineering program is focusing primarily on qualifying the students to professional engineering jobs

Whereas the Bachelor of Engineering programme is qualifying students primarily to continue their education on a Master of Science programme, with a clear aim towards a scientific career. The B.Eng. has strong bonds to industry, bonds that have been built and strengthened by the mandatory and combined industrial internship and bachelor thesis. The B.Eng. program in electronics was merged from the Danish Engineering Academy into DTU. It was from the start clear that teachers from the scientific side would gradually assume teaching responsibilities in the B.Eng. programme, the challenge at this point was: How can the B.Eng. culture with close linking between teacher-student-industry be conveyed to the new teachers?

-The B.Eng. programme has 4 mandatory semesters, internship in industry and few elective courses.

-The B.Sc. and M.Sc. programmes have many elective courses and no internship

Each of these engineering programmes is guided by competence profiles describing the competences obtained by the students. It is clear, that the B.Eng. programme is easily tailored to comply with the competence profile, because of the large mandatory contents, (in other words, highly controllable), whereas it is a challenge to assure that the B.Sc. and M.Sc. programmes comply with the competence profiles (difficult to control because of the large number of elective courses) .

DTU has in 2006 chosen the CDIO concept as the platform for developing the B.Eng. programmes [2], it will be shown in this paper, that the elements in the CDIO syllabus and the large demands of well structured documentation of the programme in fact help to assure the preservation of the culture of the B.Eng. programme, simply because it is now documented during the CDIO implementation process. An example from Swedish universities on how the documentation and implementation work on a large number of educational programmes are carried out using integrated program descriptions are found in [11] and [12]. These papers by Malmqvist et. al. give a very well structured approach, that can be used when designing new educational programmes and when generating the program plan and the course plans, which is the general method a university uses to describe its programmes to the students and the outside world. Program goals and program design matrices are used as tools to assure that program goals are fulfilled.

This paper is describing the implementation of CDIO in one engineering programme and focuses on how to assure and maintain the quality and culture of the education. In other words focus is directed towards the teachers, and the proposed master document is used to guide the teachers when they, as responsible for their course plan, maintain and teach the course. The next chapters describe first the course plan, showing the course inter dependency, the placement of cross disciplinary projects and later the master document is described with an example from a second semester course then the progression of the "soft skills" is described, discussed and proposals are given on how to assure progression in soft skills and teamwork, after that evaluation results from a course in the programme is presented followed by discussions and conclusion.

PROGRESSION OF TECHNICAL KNOWLEDGE AND REASONING

The B.Eng. program in electronics admits students both summer and winter. It has 3 progression levels on its first 4 semesters. The 1'st and 2'nd semester courses are offered both in the spring and fall semester, whereas all the remaining courses are scheduled once a year only. This is possible as there is no progression between the 3'rd and 4'th semester courses, the progression is strong from 1'st to 2'nd and from 2'nd to 3'rd and from 2'nd to 4'th semester.

From the 5'th semester the students have elective courses giving them the possibility to specialize in a field of interest, to aid the students in their selection of courses, recommended study plans for 4 different technical fields are offered, if the students prefer they can design their own individual plan, choosing from a list with more than 50 elective courses.

At the end there is 20 weeks industrial internship followed by a 10 week final project.

The DTU B.Eng. programme in electronics has 120 ECTS mandatory courses on the first 4 semesters, 30 ECTS elective courses on the 5'th semester, and 15 ECTS elective courses, on the 6'th and 7'th semesters. On the 6'th and 7'th semester the programme contains 30 ECTS industrial internship followed by 15 ECTS B.Eng. final project. The final B.Eng. project follows the internship subject closely and is normally carried out in the same industrial company as the internship, only very few final B.Eng. projects are carried out on campus.

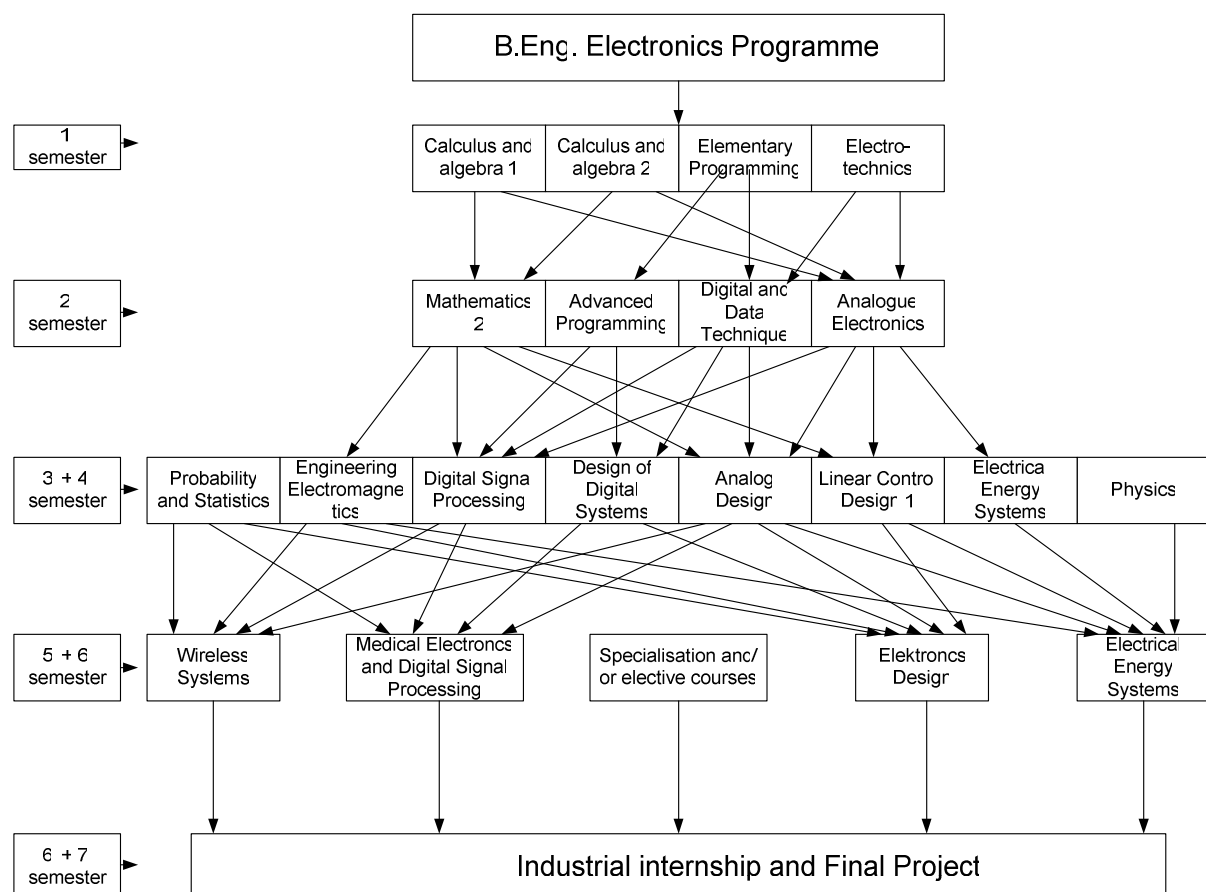


Figure 1, DTU B.Eng. programme in electronics, course progression in technical knowledge

Figure 1 depicts the course progression (from top to bottom) in the curriculum, the arrows pointing away from a particular course points towards courses that are next in the progression chain. The first four semesters are mandatory and taught using the CDIO standards. This allows that the courses are highly interlinked, both in Technical knowledge, the Personal and generic professional skills, the Social skills and in the Professional engineering skills as called for in CDIO Syllabus, the link is very strong between courses on the individual semesters and teacher teams on each semester supports this linkage by having regular meetings.

Another demand in the CDIO syllabus is the cross disciplinary projects [10] on each semester. It is therefore imperative that a teacher responsible for a cross disciplinary project understands that he must now perform in relation to a predefined educational culture as part of a large system, instead of exercising the "course owner" mindset that is often seen in free elective study programmes.

Having implemented CDIO in the program, the course catalogue contents have changed and the learning outcomes has been added into the course descriptions, Cross disciplinary and Design Build projects has been developed and implemented, Teacher teams has been formed and knowledge about CDIO has been disseminated into the teacher group

In the programme all courses contains projects of varying size, and each of the first 4 semesters contain a cross disciplinary project placed in a 3 week project period placed at the end of the semester, the project period are connected to a project carrying course which like the other courses in the semester runs for 13 weeks, two of these are CDIO Design Build courses, which are placed in the 1'st and 4'th semesters [8].

DTU B.Eng. Education in Electronics					
1. Semester	2. Semester	3. Semester	4. Semester	5. Semester	6 + 7. Semester
Calculus and algebra 1	Matematics 2	Probability and Statistics	Physics	Elective Courses	Elective Courses
Calculus and algebra 2	Advanced Programming	Engineering Electromagnetics	Design of Digital Systems		
Elementary Programming	Analog Electronics		Analogue design		
Electrotechnics		Digital and Data Technique	Linear Control Design 1		
Project in Electrotechnics	Linear Systems, Digital Signal Processing and Signal Processors		Electrical Energy Systems		

Figure 2, DTU B.Eng. program in electronics, 1'st to 4'th semester are CDIO based.

- White** : Cross Disciplinary Projects (CDP)
Light orange : Contributors to CDP
Light gray : Minor or no contribution to CDP
Dark gray : No contribution to CDP

MASTER DOCUMENT

In order to implement the CDIO syllabus a study plan committee was formed. The task of implementing the Syllabus standards in the DTU B. Eng. programme in electronics was eased due to a major revision of the study plan carried out in 2006. The primary focus on the former revision was on technical knowledge and on assuring a better progression between the courses. Due to knowledge about the upcoming CDIO implementation, places for implementing cross disciplinary courses were also pointed out. The study planning committee was therefore able to concentrate primarily on the Design Build projects and the soft skills implementation, the CDIO syllabus competences 2-4. To describe the proficiency levels of the CDIO syllabus competences, all course was assigned learning objectives using Bloom's taxonomy [6] see figure 6.

An in depth description on how the soft skills were distributed across the courses, how the competence matrix was created, and which Bloom levels was documented in a master document for the first 4 semesters in the programme.

One of the challenges that emerged quickly was the question of progression in Communication skills (CDIO Syllabus 3.2), how do we assure, that the students improve their skills in writing technical reports? How do we measure this improvement over time? And how do we distribute the responsibility for doing this between the courses.

Another challenge of a similar nature was, how do we assure progression in the students skills regarding project management, project planning and working in larger groups? And which courses are responsible for teaching these fields?

In fact a lot of critical interfaces/agreements between the courses were disclosed and many worries about this were expressed in the study planning committee because, how can it be assured, that these sometimes very fragile but important interfaces are maintained over time and when teachers change.

All courses are described in the course database [4] using a common information entry form. The course database is directed outwards towards the users, i.e. present and potential new students. Apart from this the teacher, responsible for a course, will have his personal records about how the course is taught including detailed plans, notes, examples, exercises, etc. Other student relevant material is placed on Campusnet [5], which is part of the university intranet.

The study planning committee found, that none of the above listed information storage facilities were suited to keep the information needed to document the CDIO course interfaces, the information could be left at the teachers responsible for the individual courses, but when a teacher leave the responsibility of a course to another teacher, the experience is, that much of this interface information are lost in the transition, thereby making the CDIO study plan vulnerable to personnel changes.

The solution found by the study planning committee was to write a master document [3] that keeps this information together with all other relevant information about the education. The master document contains information related to every individual course in the curriculum as well as information common to the whole programme. The structure of the master document is depicted in figure 3 and an example of one document page for one course 31022 is depicted in figure 4.

The Competence profile for the complete B.Eng. program [9]

A graphical overview of all the courses in the curriculum showing the progression of Technical knowledge and reasoning see Figure 1.

For each course in the curriculum (Figure 2)

- Progression within the field of Technical knowledge and reasoning, and collaboration between this and other courses
- Contributions to Design build project or Cross disciplinary project
- Learning objectives from the DTU version of the CDIO syllabus to be addressed during the course
- Explicit learning objectives to be placed in the course database

A figure describing the progression of CDIO syllabus top level competences

A soft skills competence matrix showing the Bloom level reached for all courses versus all CDIO competences in the CDIO Syllabus (Figure 5)

A list of all course descriptions

Figure 3, Structure of the master document

Progression within the field of “Technical knowledge and reasoning” and collaboration between this and other courses

The course builds upon the course 31031 Electrotechnics and adds competences regarding time varying signal analysis of electronic circuits.

The course contains AC and transient analysis of circuits, filter theory, semiconductors (MOSFET) DC analysis and small signal equivalents. To visualise these fields the simulation program PSpice is used.

The course exploits the subjects Laplace and Fourier analysis which are treated in the course 01964 Mathematics 2 which runs in parallel with 31022, examples from 31022 are likewise used as examples in the mathematics course

31022 contain extensive laboratory exercises and a larger project, this project is a part of the 2'nd semester cross disciplinary project performed in collaboration with the course in digital design 30080.

The course gives competences within the fields of: designing simple filter circuits using discrete components, and calculating frequency and transient responses for linear circuits.

31022 forms the basics for the advanced electronics course 31037 and control theory 31301

Design build project or Cross disciplinary project:

The project covers the production of an RIAA amplifier which are designed and implemented on a PCB

The 2'nd semester cross disciplinary course is basically an instrument designed to measure the frequency response, the instrument are used in an exercise and under the development of the filter circuit. The RIAA circuit at also used as a well defined test object during the remaining part of the cross disciplinary project.

The groups working on the RIAA projects are not necessarily the same as in the other courses on 2'nd semester

Learning objectives from the DTU syllabus to be addressed during the course

Group 2: PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES

2.2. Experimentation and knowledge discovery

Measuring methods to be used in connection with AC and transient analysis are taught in connection with the laboratory exercises and under the implementation of the filter amplifier.

Bloom level 3 (Apply)

Group 3: INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION

3.1. Teamwork

The course exploits and builds upon the acquired skills in collaboration and group work. The students must plan and distribute of work and responsibilities for the project. The work is carried out in groups of 2-4 persons. Bloom level 2 (understand)

3.2. Communication

A written report are made describing the project work- designing and implementing a filter amplifier- the report standard is applied here, half of the report is reviewed during the course and the full report evaluated as part of the oral exam. The oral examination of the course must include an oral presentation of part of the project report. Bloom level 2,3 (understand, apply)

Group 4: CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT

In the course elements of system design (4.4), implementation (4.5),and operating (4.6) are used although no specific bullets covering these aspects are added into the course description in the course base

Explicit learning objectives to be placed in the course database

- use measurement instruments and measurements to recognise circuit functionality
- documentation of project work in the form of a technical report
- cooperate in a team and delegate responsibility to team members

Figure 4. Detailed example for the 2'nd semester course "31022 Analog electronics"

PROGRESSION OF CDIO COMPETENCES "SOFT SKILLS"

Apart from the mapping of the Technical skills, as shown in figure 1, the master document also contains a mapping of courses contributing to the CDIO competences.

In order to map and assure progression in the CDIO competences, Blooms taxonomy has been chosen as the tool to describe the levels of progression expected in the different courses, and the proficiency levels reached for all courses related to the CDIO syllabus competences, the mapping is depicted in the competence matrix shown in figure 5

		2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	4.1	4.2	4.3	4.4	4.5	4.6
01906	Diplomath 1				1		1		3						
01907	Diplomath 2				1		1		3						
02318	Introductory programming for Diplom-E														
31032	Elektrotechnics		2				1								
31033	Project in Elektrotechnics	1	3	2			1	1					1		
01964	Matematiks 2				2										
31022	Analog electronics 1		3				2	2-3				1			
02319	Videregående programming for Diplom-E												2		
30080	Digital and Datateknik	2-3		3			2-3	2-3				1	2-3		
02323	Probability and Statistics				3										
31035	Applied electromagnetism		4												
31038	Linear systems and Digital signal processing	U2-3										2			
10917	Physics											U2			
31037	Analog design														
31300	Linear Control Design 1													1	
31028	Digital systems														
31036	Electrical Energy systems	4	U4	4				U3							3
praktik	Internship					2				1	1				
Final level		4	4	4	3	2	3	3	3	1	1	2	3	1	3

Figure 5, Competence matrix for the courses

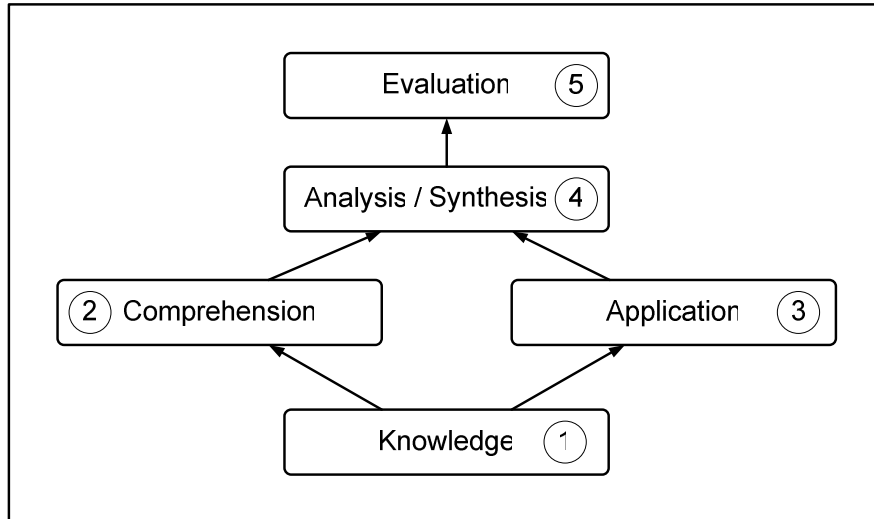


Figure 6, Blooms taxonomy simplified

A most important part of the engineering programme development and implementation is assuring good compliance with industry needs [1], at the beginning of the programme development the advisory board for the Department of Electrical Engineering was asked to evaluate the CDIO syllabus competences in relation to the electronics industries needs and rate their importance on a scale from 0 to 5. At the same time teachers responsible for the programme were asked to make an apriori competence matrix for the programme and use Blooms taxonomy to describe the proficiency levels for the CDIO competences.

At the end of the programme development an aposteori competence matrix was created based of the competences, that were the result of the programme revision, and stated in the master document. The proficiency levels of the new programme were then benchmarked in relation to the information gathered at the beginning of the programme design process, the benchmark is depicted in figure 7.

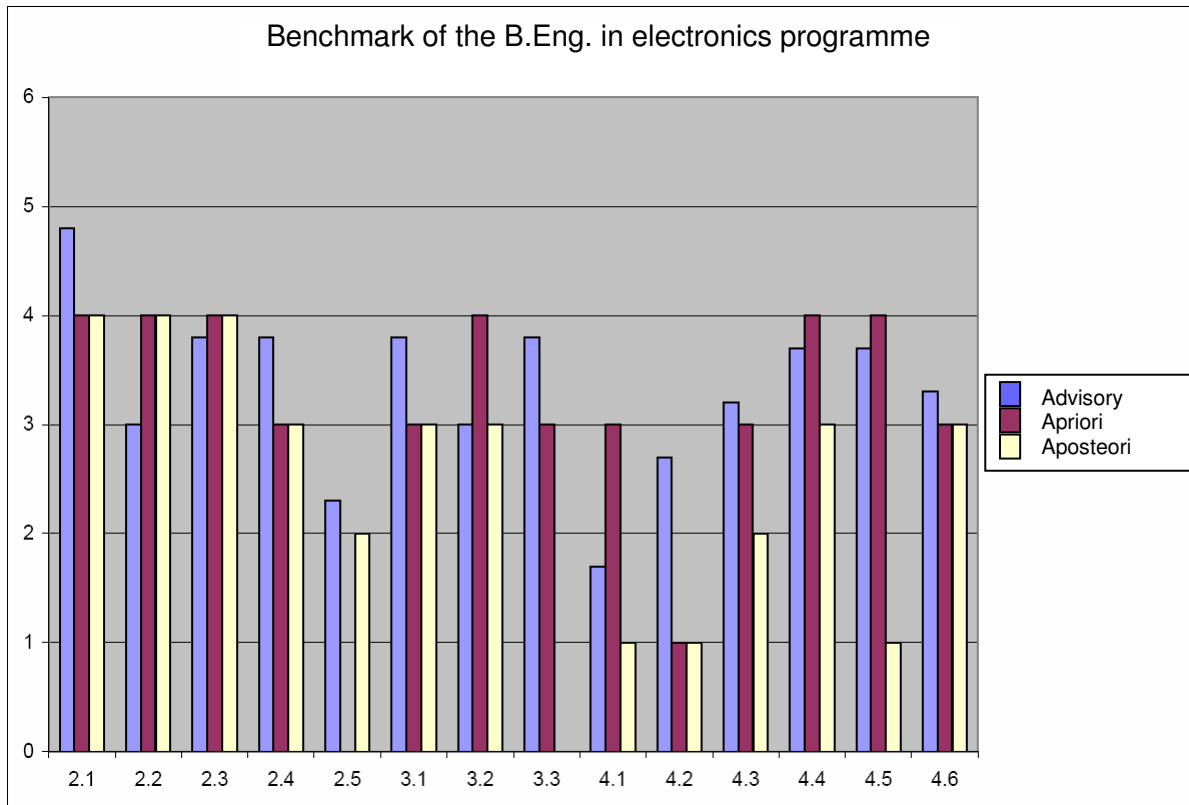


Figure 7, Benchmark of the B.Eng. in electronics programme

As figure 7 depicts importance 0-5 and bloom proficiency levels 0-5, in the same plot, a comparison can be difficult, it can however be concluded that the proficiency level obtained in the prior programme (apriori) generally have good correlation with the importance levels stated by the advisory board. The competences 4.1 “External and societal context” and 4.2 “Enterprise and Business context” have a rather low score both in importance and proficiency level.

Comparing the proficiency levels from the apriori and aposteriori matrices a good correlation exists except for the points 4.1, 4.2 Social and Business content, which shows a low weight on these topics, quite similar to the survey carried out on MIT and depicted in[7]. Also competence 4.5 is lower than expected, this is important, as it is the implementation part, the cause for the low proficiency level lies in the way the programme committee understands “implementation” in the electronic engineering context, and is not to be mistaken as an expression for low focus on implementing electronics circuits in the curriculum.

ASSESSMENT CHALLENGES IN PROGRESSION OF SOFT SKILLS

When adding the learning objectives to the course descriptions they obviously have to be testable furthermore there is a demand for progression within the skills in the 4 semester mandatory period. The study planning committee found several challenges going through the different learning objectives, especially the CDIO competence points 3 regarding teamwork and communication raised several questions.

-How is it possible to measure progression in report writing skills?

-How is it possible to measure progression in the ability to cooperate, plan and distribute workloads when working in groups?

-If testing in these skills how do we assure that the assessment by teachers on different semesters fits the level expected?

For reporting skills a teacher might rate a report from a first semester student as poor compared to a 4 semester students report with much more experience, this would be a serious mistake, as the reporting skills are expected to improve over time.

It is necessary to describe which report levels are expected for each of the 4 semesters to assure, that the students know what level to comply to, and similar to the teachers what they should expect, when they grade the reports. Having a common reporting standard was discussed, but has not been implemented, because there are among the teacher group variations in the way they view reports, and also because different tasks calls for different report types. Instead the students are gradually exposed to the topics, following the path described below.

Report writing skills:

1'st semester:

A partially filled report is handed out to the students, and the students add their contributions/results into this report.

2'nd semester:

A partially filled report is handed out to the students and the student add their contributions into this report, the students submits their report for review and receive the reviewers (teachers) comments, the student adjust the report according to the received feedback and resubmits the report.

3'rd-4'th semester:

The students submit full reports

Ability to cooperate, plan and distribute work when working in groups:

1'st semester:

In the Design Build project the group size is 2-3 persons, the group has to write a small project plan consisting of delegation of responsibility for different tasks in the project, and also a Gant plot showing resource allocation over time.

4'th semester:

In the Design Build project the group size is 10 persons, here the project management part is larger because of the large group, group leadership, and group meetings are now necessary elements that has to be carried out in order to utilize the large amount of working hours in a sensible matter. Some lectures are given in the subject of project management, and reference material is available.

Figure 8, Progression in soft skills related to CDIO syllabus Group 3: Interpersonal skills, teamwork and communication.

IMPROVED STUDENT EVALUATIONS

Evaluation of the effect on the learning outcome as a result of implementing CDIO elements should preferably be based on evaluation before and after the implementation with all other factors unchanged. The courses 31022 Analog Electronics (described in figure 4), had a major change to fit the new CDIO requirements, and is otherwise unchanged (The technical and scientific curriculum, as well as the textbooks and the teacher, were the same).

All courses in a semester are at DTU evaluated by the students using a standardized questionnaire. The result is shown in figure 9 for the course from 2007 to 2010 (prior to 2007 the questionnaires were not comparable).

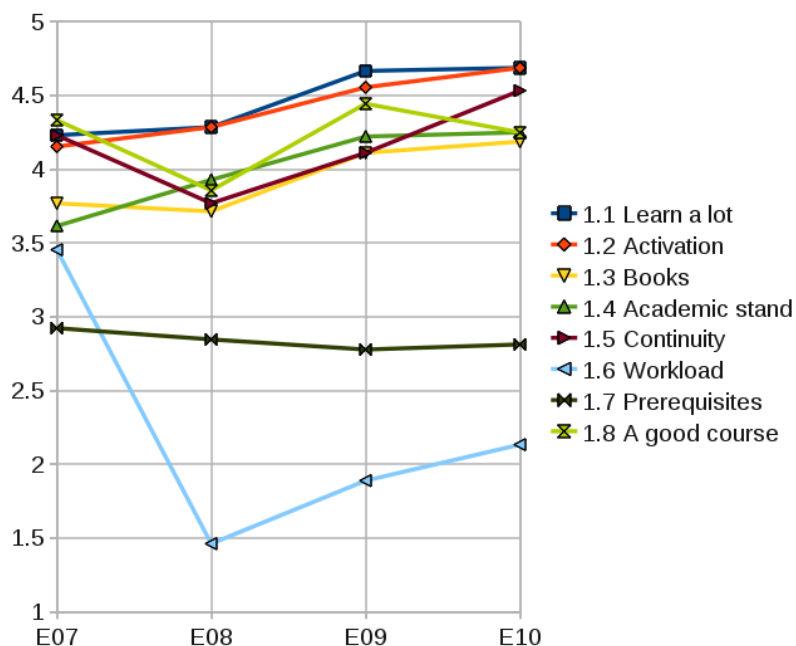


Figure 9: Development in average student evaluation of the 31022 course.

The CDIO elements were introduced in the fall 2008 (E08). The work load increased significantly, but so did the general satisfaction with the course. The scale 5 is strongly agree and 1 is strongly disagree for a positive formulated question, for work load 5 is much less and 1 is much more than the norm.

Six of the eight questions were formulated positive on the subjects indicated on figure 9, where 5 is strongly agree to the question and 1 strongly disagree. For the work load the scale is 5 for much less and 1 for much more than the norm for 10 ECTS points. For Prerequisite requirements the scale is 5 for too low and 1 for too high.

The CDIO elements were introduced in 2008 – with the main element being a continued project, where a partially completed report twice has to be handed in for review, and the complete report at the end. The lectures and related exercises were further adjusted and rescheduled to fit the progress in the project.

The major change in student evaluations was in the work load, where the new method required much more work. At the same time the satisfaction with the course did not drop, and at the next course, after some streamlining, the satisfaction level increased significantly, and maintaining the rather high workload at the same time.

This positive outcome can only be seen as a consequence of the changes introduced based on the added soft skill learning objectives and the new teaching attitude from the work with CDIO.

One of the student comments, after the course in 2009, is almost too good to be ignored: "The course is well planned, and almost the mother of all courses. The practical parts make it compelling to know the theory, and at the same time create curiosity for the subject." (Translated from Danish).

DISCUSSION

Benefits

The benefits of having a master document are numerous, it can be used when:

- presenting the course for potential new teachers, to show in depth what is expected
- presenting the education as a whole, one source of info controls the whole education
- describing the agreements made between courses coming from different institutes
- describing the hard skills interfaces in the form where do we come from and where do we go, summing up which skills are prerequisites for courses on later semesters.
- describing the course role and contribution to a cross disciplinary project
- describing the design build project if one exist in the course
- describing which soft skills should be taught in the course
- stating the level of soft skills taught in the course
- teacher's coming from other educational levels needs help to adapt to the methods and levels in the course.

Future Challenges

The master document has been designed and 1'st and 2'nd semester courses and cross disciplinary projects has been described in the document, 3'rd and 4'th semester courses have only been given one time and are still in the moulding process the master document is therefore not complete on these semesters and some further work is necessary to complete the document.

The teacher's response to the master document has to be evaluated.

All individual courses are evaluated at the end of the semester, figure 9 depicts the result of one of the courses in the programme but similar comparisons has to be performed over the remaining courses and an analysis on the whole program has to be made.

Furthermore the programme is audited on a 5 year interval basis and an audit as a CDIO based program has not yet been scheduled.

CONCLUSION

The work done implementing CDIO in the B.Eng. in electronics programme has shown, that during the process of building an educational programme, much information are generated and many decisions made in order to produce the program plan and the corresponding course plans containing the learning outcomes for the courses.

The master document proposed complement the course plans, by keeping the records of exactly why a particular learning outcome has been put in the course plan, and what particular obligations the course have in relation to the whole program. The value of having the master document will grow with time, as the program matures, in fact it has already proven to be very useful in a situation, where a teacher heavily involved in the CDIO implementation had to be replaced. The master document also assures, that the quality and especially the culture in the education can be maintained for as long, as it is found necessary.

The document of cause has to be reviewed on a regular basis and also modified according to the changing demands on the education.

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Biographical Information

Claus Kjærgaard received the B.Eng. (hon.) in electronics engineering from the Danish Engineering Academy 1984. In 1987 he joined the Danish Engineering Academy, which is now part of DTU. He is currently an Associate Professor at the Department of Electrical Engineering, DTU. For many years his research was focused on reliability of repairable electronic systems. During the last 10 years his work has been focused on teaching and developing courses and study plans in the field of analog electronics and hybrid microelectronics and on research in these fields. In 2006 he received the reward as best teacher in the B.Eng. educational programs at DTU. Since 2005 he has been head of studies for the B.Eng. program in electronics and has been responsible for the implementation of CDIO in this program.

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SYSTEM ENGINEERING IN SENIOR-DESIGN CAPSTONE PROJECTS

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ABSTRACT

The United States Naval Academy (USNA) is an undergraduate-only institution whose mission is to educate future officers in the United States Navy and Marine Corps. The Naval Academy has participated in a number of project based learning efforts both in engineering classes (Design–Build–Fly) as well as in focused projects (e.g. SAE Formula-1 race car, Cockpit of the Future, and the Sailbot). We are currently participating in the Systems Engineering Research Center research topic “RT-19: Research on Building Education & Workforce Capacity in Systems Engineering” (RT-19) for the 2010–2011 academic year. Research topic RT-19 is to develop Systems Engineering talent in the workforce through projects developing working solutions to real-world problems. USNA RT-19 participation includes sixteen students from four majors and three departments working on four independent senior-design capstone projects:

- Improving Surge Power Capabilities.
- Personnel Tracking.
- Portable Low-power Water Purification (interdisciplinary project).
- Portable Renewable Sea-based Power Generation, Storage, and Distribution (interdisciplinary project).

Each team is developing a functioning artifact that could be delivered to the RT-19 sponsor as a prototype implementation. The projects were conceived to solve a specific problem, designed to be viable within senior-design course limitations, and implemented by the students. They will be demonstrated as part of capstone presentations in April.

We have faced two challenges so far. The first challenge has been interdisciplinary project coordination in the presence of different senior-design sequences with different schedules, course content, and course requirements. The second challenge has been providing systems-engineering content without a common senior-design sequence for interdisciplinary project teams.

In this paper, we provide a full accounting of our experiences to date including accomplishments, lessons learned, and our plans to improve the senior-design process to support both well-defined as well as quick-reaction project opportunities.

KEYWORDS

Systems Engineering, interdisciplinary team, capstone project.

INTRODUCTION TO THE USNA RT-19 EFFORT

The United States Naval Academy (USNA) is an undergraduate-only institution whose mission is to educate future officers in the United States Navy and Marine Corps. There has been a significant increase in recent years in the emphasis on laboratory and project-based-learning in many science and engineering courses for majors and non-majors alike. The Naval Academy has participated in a number of project based learning efforts both in engineering classes (Design–Build–Fly) as well as in focused projects (e.g. SAE Formula-1 race car, Cockpit of the Future, and the Sailbot). At the Naval Academy, student time is a scarce resource with many academic, military, and physical requirements competing for a share; unlike most academic institutions, student time is even committed during Summer. Project work, as important as it clearly is, must be bounded in both time and complexity so that it can be completed successfully by students in light of the many competing requirements for their time. We always strive to find and support projects that can develop and lead students into new opportunities in both their military and eventual civilian careers.

The Naval Academy is currently participating in the Systems Engineering Research Center research topic “RT-19: Research on Building Education & Workforce Capacity in Systems Engineering” (RT-19) for the 2010–2011 academic year. RT-19 enables participating institutions to develop programs that educate students in a technical area that has significant growth and opportunity both within the military and in industry. The purpose of research topic RT-19 is “to pilot innovative strategies to increase learning and career awareness of systems engineering through capstone courses during the 2010-11 academic year.... A 45% growth is expected in SE jobs in the next decade and there have been numerous studies and workshops that have highlighted the shortfalls in both the number and capability of the SE workforce” [1]. It is a step toward addressing this problem through development of project-based learning curricula and the integration of Systems Engineering coursework for senior-design capstone courses. At the end of the academic year, all participants in research topic RT-19 will be meeting to share the lessons learned so that they can be incorporated in future senior-design capstone courses. We also plan on feeding these various learnings back into our senior-design capstone courses over the summer so that improvements based on this year's experiences are in place for senior-design projects next academic year.

Key to RT-19 is the application of Systems Engineering to senior-design capstone courses. In RT-19, as in our current courses, the senior-design capstone courses involve significant projects that are focused on developing solutions to real-world problems; what is added with RT-19 is an emphasis on the development and application of Systems Engineering skills and methods. For the 2010–2011 academic year, USNA RT-19 participation includes sixteen students from four majors and three departments working on four independent design projects. The students involved in these projects have already gone through the first three CDIO phases: they first conceived solutions to specific problems (selected and specified by them from a set of basic problem and project areas provided by the RT-19 sponsor), then they designed and implemented systems based on their solutions. Each of these design projects is developing a functioning artifact that could be delivered to the RT-19 sponsor as a functioning prototype. The students have finished their implementations and have presented their efforts and demonstrated their operation them to their departments as well RT-19 program sponsors and staff; they all successfully demonstrated their efforts in as the finale of their senior-design capstone experience.

The four RT-19 senior-design capstone projects that students worked on are as follows:

- Improving Surge Power Capabilities: develop a means to scale power-generation capacity dynamically consistent with power demand.
- Personnel Tracking: develop a distributed and portable system to track personnel and to produce status reports on demand in both routine and emergency situations.

- Portable Low-power Water Purification (interdisciplinary project): develop a water-purification system to produce pure water in stand-alone applications supporting up to 150 personnel.
- Portable Renewable Sea-based Power Generation, Storage, and Distribution (interdisciplinary project): develop a wave-power generation system that is highly portable and easily deployed to provide power in stand-alone applications supporting up to 150 personnel.

We have faced two significant challenges so far. The first challenge has been interdisciplinary project coordination. This challenge has been difficult because each department has its own senior-design sequence with different schedules, different course content, and different course requirements. The second challenge has been systems engineering curriculum integration for the students participating in research topic RT-19. We have had mixed results in developing workarounds to these challenges. However, we are working on adjusting departmental senior-design project calendars to enable better support for interdisciplinary projects and will provide feedback to the RT-19 sponsor on how to better match their research programs with academic schedules. Solving the timeline mismatch between funding-agency and academic-year schedules is a more general and difficult problem that is beyond the scope of what we are discussing in this paper.

In the rest of the paper, we describe our RT-19 effort. First, we describe how we integrated Systems Engineering content into the senior-design capstone process; then we introduce how we managed interdisciplinary projects. Next, we cover the four projects and evaluate how well they achieved the main research topic RT-19 and CDIO Standard aspects. Finally, we discuss the key lessons learned from our participation in RT-19 and how we are using these learnings to improve our senior-design capstone courses—both from the perspective of participating in an externally-driven senior-design project with its own requirements as well as from the perspective of delivering a successful senior-design capstone program.

SYSTEMS ENGINEERING INTEGRATION

Research topic RT-19 is focused on improving the Systems Engineering capabilities of students in engineering programs, especially in those schools like the Naval Academy which do not have traditional Systems Engineering majors. The International Council on Systems Engineering (INCOSE) describes Systems Engineering as “an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem” [2]. In contrast, at the Naval Academy the Systems Engineering major “prepares students to integrate mechanical, electrical and computer systems in an effort to automate different processes. Some of our main applications include Robotics, Unmanned Vehicles, Computer Vision, Guidance Systems and Sensor Technology. At other schools we would be called Mechatronics or perhaps Feedback Control Systems” [3]. The Department of Weapons and Systems Engineering, like all of the engineering departments, includes some Systems Engineering concepts as part of the senior-design capstone courses but they are not presented as part of a complete process for managing and realizing complex systems.

There were two basic requirements in this area: first, to integrate Systems Engineering coursework into the curriculum; second, to include Systems Engineering processes into senior-design capstone projects. In this case, because of our registration and scheduling timeline at the Naval Academy, class selections and student schedules were fixed before research topic RT-19 was announced; an added problem was that projects and teams were not organized until well into the fall semester shortening the time available for delivering the Systems Engineering content. As a result of these schedule-related issues, we decided to

take advantage of existing web-based course delivery from the United States Defense Acquisition University to deliver a combination of acquisition and systems engineering coursework on an independent-study basis. In addition to making course delivery as flexible as possible (having a recommended module completion schedule but no specific work schedule and only a few hard course completion deadlines), an added benefit was requiring specific courses that would enable future certification as a Systems Engineering acquisition professional (in accordance with the United States Defense Acquisition Workforce Improvement Act).

This choice proved to be unsatisfactory in an undergraduate environment due to both course content (the courses were overly focused on bureaucratic aspects of acquisition and systems engineering) and policy (the courses followed a “three-strikes and you’re out” policy that had students restart the course if they failed to get a perfect score on a subject-area exam three times). An additional complication was that the courses were not organized for group delivery and progress tracking with the consequence that many students were caught well behind at scheduled completion deadlines and a number of them rushed through the courses, failing a subject-area exam three times, and were then forced to do a complete restart on the course with all of their successfully-completed material discarded. The end result is that all but one of the students completed the required courses successfully, but they focused more on completion than comprehension and thus, unfortunately, failed to learn the relevant Systems Engineering content to a sufficient degree that they could apply it significantly in their projects. However, although the specific web-based courses that we used were problematic in content, policy, and delivery, we believe that there is a strong potential to migrate some course material into web-based courseware to complement in-class delivery of related material and intend to investigate this solution in the future.

In spite of the difficulty with focused delivery of Systems Engineering coursework, all of the project teams were encouraged by their mentors to apply Systems Engineering processes to their projects. In particular, students were encouraged to define requirements and to design their systems to meet those requirements. Where possible (especially in the two interdisciplinary projects), the students were encouraged to design modular systems both to make the designs more flexible as well as to distribute the load across different subgroups of students during the project.

INTERDISCIPLINARY PROJECTS

The problem areas specified by research topic RT-19 were diverse; our projects were selected from these project areas and two of them, unsurprisingly the larger two projects, were also interdisciplinary—this aspect of the projects was one of the main reasons that participating in RT-19 was compelling. In particular, coordinating the interdisciplinary projects has been particularly difficult because students on the project were on different schedules and in different senior-design capstone classes. Unfortunately, the late start for research topic RT-19 resulted in such a late timeline that it limited our ability to organize to support interdisciplinary projects. Because of the nature of the Naval Academy, student schedules are very full and fairly rigid once they are defined—class preparations were complete and student class assignments and schedules already fixed, both were accomplished without consideration of research topic RT-19 requirements as the details on RT-19 were not available until just before the fall semester began. In addition, project selections did not occur until the semester was well underway making schedule revisions (including the likelihood of multiple class or section changes) unreasonable. Thus, the students who ultimately chose to perform senior-design capstone projects under research topic RT-19 were already distributed across multiple classes in the three departments and chose to do these projects knowing the difficulty that they would likely face.

Starting up the interdisciplinary projects proved to be the most difficult aspect of our RT-19 effort because it was particularly arduous to get the students on these projects to coalesce into a team and to define their project direction to the point that the different student groups (in different classes) could break off and make forward progress independently. This problem was exacerbated by the fact that each department had different class schedules and assignments which meant that even when the students could get together, they were often working on different aspects of the problem to meet their own course content and assignment deadlines. However, once the students were able to reach the point of basic project definition and partitioning, they were able to distribute the work among subgroups and made solid forward progress—unfortunately delayed from what might have been, but more than reasonable given the coordination difficulties from having different subgroups working on the same project.

CAPSTONE PROJECTS

The USNA RT-19 effort comprises four independent projects undertaken by sixteen students from four majors and three departments; there were six civilian and military faculty mentors supporting these projects. This section summarizes the projects and reports on student successes and failures as they went through the RT-19 effort.

Improving Surge Power Capabilities

The Surge Power Capabilities project comprised one Electrical Engineering student; the project was originally a two-student project but one student changed projects at the last minute which proved to be the limiting factor for what the remaining student could accomplish during the project. The fundamental problem that this project was intended to address was the dynamic nature of expeditionary power grids and its impact on fuel consumption in expeditionary or humanitarian-relief camps of approximately 150 people. For this project the student selected a primary and alternate power source as well as a dynamic load to research the feasibility of dynamic load balancing between two power sources. Testing of this concept required the student to integrate the two sources so that the load could be transfer alternately from one source to the other and some method of measure the current transients.

The student that selected this project conceived of using a bank of four car batteries connected together to create a 24 VDC alternate energy source; the intent was to model the HMMWV vehicle batteries that are in common use in camps. The student used a standard 120 VAC gasoline generator to model the primary power source and used large residential HVAC units to represent the dynamic loads. Although the student initially expected to use a simplistic circuit for connecting the sources two sources to the load, the student soon realized the complexity of a realistic high power component interconnection. Ultimately, the student designed a 24 VDC bus that both power sources could be individually connected to and disconnected from; 120 VAC power to power the dynamic loads is produced using power inverter off of the 24 VDC bus. To be able to connect the generator to the 24 VDC bus the student designed a high voltage rectifier to convert the voltage from 120 VAC to 120 DC and buck chopper to drop the voltage to 24 VDC. Both circuits are common and frequently used but not commonly in 5000 W power range. This project required the student to conduct an in-depth study of power electronics and heat dissipation in order to specify the necessary components as well as to consider the mechanical aspects of circuit design to provide sufficient thermal dissipation when the circuit was under load.

The completed system will be able to serve as a test bed for further research on providing power to dynamic power grids from multiple sources. It also has great potential for future student projects in control automation and algorithms to improve efficiency.

Personnel Tracking

The Personnel Tracking project comprised two Computer Engineering students who developed a Personnel Tracking system that replaces paper logs and reports with mobile devices connected to a dedicated server system. In addition to using a dedicated base station, the system is designed to be able to use ad hoc communications to enable continued operation during power losses or emergencies requiring facility evacuation.

Following the initial conception of their project, the students defined the project in terms of required capabilities. They then designed the overall system architecture and selected the hardware to meet those requirements. Next they built paper versions of the software interface to enter, search, and view personnel status. In parallel with basic system and software architecture, the students also ramped up on wireless propagation models.

The students have implemented a basic application on a mobile device (Apple iPod Touch) that is able to scan the barcode on student IDs (using the Infinite Peripherals Linea-pro barcode scanner/magnetic stripe reader); the application on the mobile device combines the barcode information with manually-entered status information and wirelessly updates the personnel-status database on a remote server. They have also performed a characterization wireless signal study within the main student dormitory complex and produced a propagation-loss model for mobile devices connecting to the fixed wireless network; they are also working on an outdoor propagation-loss model assuming mobile devices only. They are using this information to determine how many access points are required within the building as well as suitability of outdoor ad-hoc wireless networks to achieve the connectivity to support the necessary connectivity. The product from this effort is the fixed-location server system and access points as well as the software and mobile devices to allow basic use.

Due to problems obtaining a development license required to program the mobile devices, the project was delayed significantly and the students were only able to complete part of the actual system implementation as a proof of concept. In particular, software development is not where they had originally planned it to be and does not include full flexibility on status input or the end-user application to produce the reports. However, the current proof-of-concept application and wireless propagation model demonstrates that their system architecture and basic implementation are reasonable for the dormitory complex and the outside emergency assembly points.

Portable Low-Power Water Purification

The Portable Low-Power Water Purification project team comprised three Systems (Controls) Engineers and one Electrical Engineer. The goal was to provide water in expeditionary or humanitarian-relief camps of approximately 150 people. During the fall semester, the team conducted extensive research to try to determine the best approach for making potable water with the least power consumption. Two key areas emerged for study: “what is potable water?” and “how is potable water made?”. The team researched current systems being used in expeditionary camps as well as other potential implementation options.

Analysis of requirements included project break down into three key functional areas as shown in Figure 1. The team then analyzed the project break down using a free mind chart to delineate what was needed as seen in Figure 2.

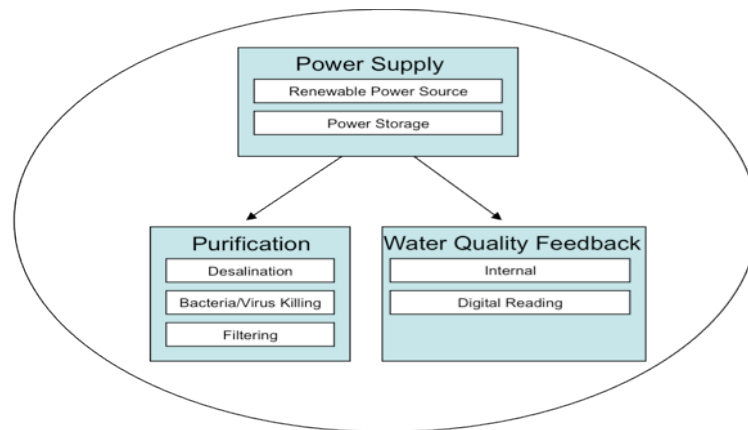


Figure 1: Low-Power Water Purification system structure

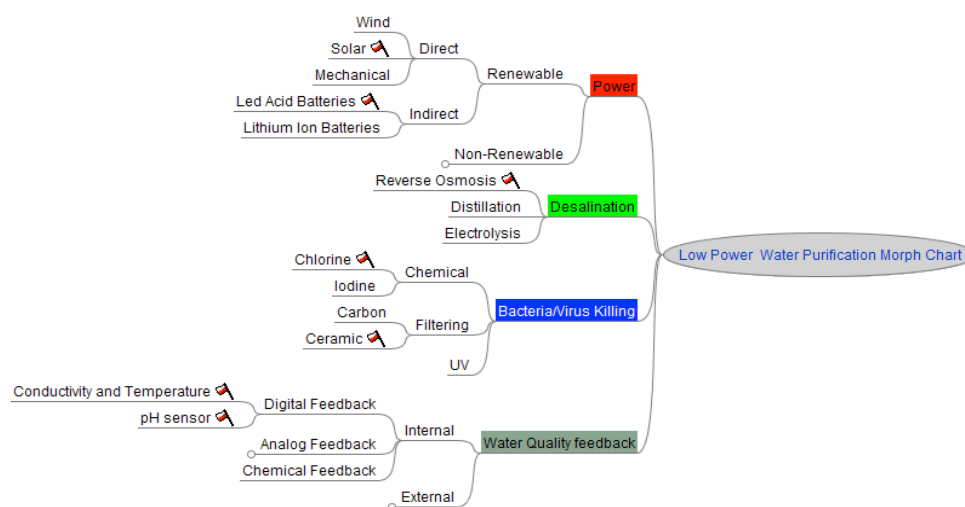


Figure 2: Low-Power Water Purification system Mind Map

The initial concept was refined during the fall semester with a design concept revolving around the use of reverse-osmosis units. Once that key design decision was made, further work went into energy generation and storage methods to include solar panels and NiMH batteries. Lead acid batteries have been used in the shop for routine testing and power applications to minimize costs as the design was being built and to keep the build process constant as acquisition of NiMH batteries, charger, solar panels was in process.

A key design and acquisition component of the project, aside from the reverse osmosis unit and the power generation and storage system, has been a sensor suite to enable the Low-Power Water Purification project to determine what exactly is needed to take source water and turn it into potable water. The team decided that the best way to make potable water with low power consumption was to first determine the initial water quality level and then determine what level of purification is required to make the water potable. Previous to this design approach, all water, independent of its initial quality, was being put through the entire purification process in a given water-purification system. To reduce power consumption without adversely reducing safety or quality of the potable water, the students decided to use a laptop computer interfaced to a water-quality sensor system; the computer then controls a set of valves which direct the feed water supply through only those purification stages determined necessary to produce potable water. By bypassing unneeded systems, there would be a power savings while continuing to produce the desired quality of potable water.

Obtaining the required parts has been difficult due to cost limits and processing delays. These delays have not only delayed initial project setup but also limited the possible system improvements of the design as it has matured from a paper concept to a functional system.

At the time of this writing, the Low-Power Water Purification system is being assembled after testing each individual component. The team has put the system together without the sensors to test for pressure drops and valve operation. Using salt water as the initial water source, the system works without incident. But the freshwater side has some pump pressure issues, probably due to the pump itself; the students continue to work on identifying and resolving this problem. The students have produced a graphical interface on the laptop computer which works well displaying status and controlling valve operations. The overall system is working as expected despite a few minor problems along the way.

Power measurements are not complete and it is currently unknown how effectively the system produces potable water at low power; this work is underway and the students expect to be able to discuss the power breakdown of their purification process in their final project reports. One goal is to determine how to optimize the process better using control algorithms (consuming the sensor data) on the laptop computer. If the project receives continued funding for next year, further work would refine the original design for further power consumption declines based on both improving the control algorithms as well as refining the system and components to overcome both efficiency and quality issues. One avenue not fully explored this year is optimizing motor selection for this application; the students identified other motors that are available but could not be purchased in time for the project due to cost (which exceeded direct purchasing limits) but which have low power consumption. Other work will improve solar panel utilization and efficiency when charging batteries, especially during cloudy conditions; this issue has proven difficult and the only current off the shelf system to offer any promise in efficiently storing energy under these conditions seems to be a fly-wheel storage system which would be way too large and way too expensive to use in this small prototype development.

Portable Renewable Sea-Based Power Generation, Storage, and Distribution

The Portable Renewable Sea-Based Power Generation, Storage and Distribution project comprised six Ocean Engineering students and three Electrical Engineering students who designed and built a linearly-moving wave-action electrical power generator. Initial design challenges included resolving the competing requirements regarding power generation and portability. Specifically, the students determined that they would not be able to build a power system that is backpack portable for expeditionary or humanitarian-relief camps of approximately 150 people. The team decided to focus on achieving a desired power generation capacity of 4,000 to 6,000 watts per unit and to keep the system portable by small military vehicles (zodiac boats or HMMWV vehicles). In order to more accurately determine the required size of a 4,000 to 6,000 watt wave-action generator, the students decided to build a smaller, approximately quarter-scale prototype model first. The Electrical Engineering students focused on designing and building a permanent magnet generator with the magnets on a moving member vertically translating up and down through the center of a set of cylindrically wound stator windings; designing and building rectification and battery charge control systems; and putting together the battery storage bank itself. The Ocean Engineering students focused on designing and building waterproof enclosures for the stator windings and the permanent magnet moving member; designing and building an anchoring system that would keep the positively buoyant stator assembly near the seabed; and designing and building a buoy system that would provide the motive force necessary to move the permanent magnet assembly up and down through the stator assembly.

The development of good inter-disciplinary communication skills was essential to this project in that members of each discipline had to be able to articulate design constraints to members of the other discipline. As an example, the Ocean Engineering students did not fully appreciate the size and weight of electrical components necessary to generate the desired electrical power and the Electrical Engineering students did not fully appreciate the challenges associated with waterproofing a moving (i.e., variable geometry) device. By being able to communicate, understand, and resolve these challenges, the students were able to complete the construction of a working prototype generator.

The team succeeded in the design and construction of the smaller, operational, prototype generator to include final assembly and testing with various wave periods in the Naval Academy's 380 foot tow tank. Due to initial purchasing delays and the long lead time associated with certain components of a full-sized system (the larger magnets require custom fabrication), the students were not able to complete the larger, full-scale design within the time period of the project (approximately seven months). Their continuing analysis of the prototype's operation and their lessons learned, however, will enable a follow-on project team to undertake the scaled design and construction of a larger system.

LESSONS LEARNED FROM THE USNA RT-19 EFFORT

As with any program, the authors along with the student teams learned many lessons as we participated in research topic RT-19. The most obvious lesson learned (again) is that it is undesirable to create project teams that are unable to work closely together. Other lessons learned are incidental (and, to a degree, consequential) from this issue: having separate classes drove the move toward web-based learning which proved to be very ineffective and frustrating for the students; having separate course requirements made interdisciplinary planning difficult as the students in different classes (and departments) learned different design processes and thus students affected by this situation had to plan and prepare different assignments on the same project as a consequence of these different classes.

Because of the nature of the Naval Academy, student schedules are very full and fairly rigid once they are defined. Ideally, research topic RT-19 requirements would have been available early enough in the Spring that we could have attracted interested students, selected projects, and assigned students on these projects them into common senior-design classes. In our case, although the goal of having interdisciplinary projects hosted by the participating departments was laudable, hindsight shows that we should have backed off on that goal and created (or partitioned) projects so that students participated within their scheduled class, not across classes. With this solution, we would have lost the interdisciplinary nature of the projects but could have focused much better on both the Systems Engineering coursework (as available within each class) and the projects. One of our recommendations back to the RT-19 sponsor will be to ensure that for future projects they engage with schools early enough that the schools can plan to support the effort and engage students early enough that they select projects and are assigned into common senior-design classes for each project.

One recurring problem that we faced on all projects related to purchasing required materials for the projects. We started off behind because access to the funds were delayed for several months; we were finally able to start purchasing about half way through the project window and the students still had to learn how to work effectively within the purchasing system which took additional precious time to navigate. The late start meant that we no longer had time to use the regular contracting process so the project teams had to redesign their systems to use low-cost items that could be purchased directly without requiring contracting. There were only a few items that ended up posing problems with this process, but eventually the students found ways to engineer the system in spite of these non-technical challenges. In

addition, even with the use of direct purchasing, getting through the purchase process took longer than the students expected, even when they had all of the paperwork in order when submitted. Going into future projects, although funds availability and purchase-request processing are beyond our direct control, we will ensure that students learn the general purchasing requirements early on to avoid unnecessary delays that are within our control.

There are several alternatives that could be explored to avoid the need to back off of the interdisciplinary aspects. One alternative would be to have separate classes targeting interdisciplinary projects and to have students from participating departments register for these classes with the expectation of being on a to-be-determined interdisciplinary project. Not only would this approach enable students to develop interdisciplinary projects, but it would also enable last-minute project sources such as arose with research topic RT-19. These classes could be taught by any of the participating departments but would allow students from each of the participating departments to enroll and still meet the senior-design capstone class requirements of their own department.

Another alternative would be for all departments to schedule all senior-design classes during the same times. Although each class would be taught by different departments, they would have similar schedule, content, and requirements to facilitate students moving between classes or sections as projects are selected. This approach is more difficult to achieve than having a few specified interdisciplinary-project classes due to space and resource constraints.

On the integration of Systems Engineering coursework, we would not repeat our choice of web-based learning to deliver the Systems Engineering course content. Although web-based learning can be effective, it must be well targeted to the goals of the project (these courses were not) and it must be supplemented with coordinated classroom learning (which was not possible in our circumstance). There is clearly value in researching (or developing) suitable web-based learning to augment classroom learning. However, even if well suited to the subject matter and audience, web-based courses should not be the cornerstone delivery method used to incorporate Systems Engineering coverage into classes; instead web-based courses should supplement and integrate material introduced and discussed in class.

The authors plan on conducting more interdisciplinary projects in the future and will leverage the experiences from participation in research topic RT-19 to make these projects more effective learning experiences. There are several other current interdisciplinary projects at the Naval Academy (e.g. SAE Formula-1 race car, Cockpit of the Future, and the Sailbot) but these are generally large-scale multi-year projects with faculty and staff supporting the projects for multiple years. There is a significant opportunity to have more flexibility in interdisciplinary senior-design projects beyond these large-scale dedicated projects. And, as illustrated in these examples, smaller-scale projects such as the RT-19 projects described in this paper may have immediate relevance and applicability in solving urgent problems that are currently faced around the world. We intend to pursue these kinds of smaller-scale interdisciplinary projects in the future to complement the large-scale multi-year projects and provide design experiences that are responsive to real-world needs.

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coursework and project requirements that their colleagues in projects not supported through RT-19 did not have to complete.

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ABSTRACT

The Basic Engineering Project is a second year subject which represents the second of four steps in the design-implement subjects path of the Telecom BCN curricula. The first one is included into the Introduction to Engineering subject and the last one is the degree Thesis. While the first and third year projects have a wide scope (from client specification to business idea), the second year project emphasizes on the technical design, implementation and characterization of a given block from its specifications but understanding the whole system concept and has a higher technical difficulty. A complex ICT system is split in blocks. All students should know the block structure but a given work team will only develop one of the system blocks. The structure of laboratory groups allows that students could select the block according to the major they will choose the following year (electronics, networks, audiovisual systems and communications). The course structure design includes three initial sessions oriented to provide disciplinary contents related with the project topic using the puzzle methodology. Then the block to be designed is fully specified and documented in the Requirements Specification document. The following 10 sessions are devoted to the design, prototyping and validation of the chosen system block. Their schedule is determined by the time plan and work package organisation that the work teams prepare and write in the Project Plan document. The preliminary and critical design reviews are performed during two progress meetings in the 7th and 11th week. This first year of implementation, the product to be designed, that has been divided in blocks is an in-home audio system component. Given that the course is running this first year with a pilot group of 24 students, only the amplifier and preequalizer blocks have been designed and built by the students.

KEYWORDS

Design-build subject, Electronic Engineering, Audiovisual Engineering, Project-based Learning.

INTRODUCTION: THE DESIGN-BUILD SUBJECTS PATH AT TELECOM-BCN

Five new bachelor degrees (4 year-long) have started this 2010-2011 academic year at Telecom BCN, the Electrical and Telecom Engineering School of the Technical University of Catalonia (UPC). Two of them (Audiovisual Systems Engineering and Electronics Engineering) already started the last academic year as pilot courses and the remaining three degrees (Communication Systems Engineering, Networks, and Telecom Science and Technology) are now running the second semester.

According to the CDIO Standards, we designed the curricula structure using a mixed approach to integrate CDIO skills into the curricula: On the one hand, the skills pathways were defined by involving all courses. Every course may contribute to the learning of several skills at a given level (basic, medium, advanced) and should actively contribute to develop and assess two of them. On the other hand, four specific project-centered courses have been scattered along the curricula, at the second semester of each academic year. They all include design-build activities and put emphasis on the CDIO Syllabus fourth group of skills. Table 1 shows their main characteristics.

Table 1
Project subjects along the curriculum

Subject	Semester	Credits (hours)	Main topics and characteristics	Group size
Introduction to Engineering	2	6 (150)	System view Basic economics Project management Seminars Partially guided project (2.4 ECTS)	4
Basic Engineering Project	4	6 (150)	Regulatory aspects of ICT (2 ECTS) Open basic engineering project (4 ECTS) Focus on design and implementation of a given block of a complex system	4-6
Advanced Engineering Project	6	12 (300)	Seminars (< 20%) Whole design and implementation of an advanced and complex engineering project Different topic per group Focus on conception, innovation and entrepreneurship	9-12
Thesis project	8	24 (600)	Individual (by Spanish law) Performed in a company or research group, on campus or in an international exchange.	1

Last academic year, 56 students from the two pilot degrees followed the *Introduction to Engineering* subject. The experience was reported in the 2010 CDIO Conference [1]. This year, 240 students are running it. Meanwhile, 24 students from the first cohort are taking the pilot course of the second design-build subject, the *Basic Engineering Project*.

The scope balance of the design-build subjects of the first three years is similar to that reported in [2], although the implementation of the first year project is quite different. The scopes of the first and third projects are wide while the second one is narrower. The depth, of course, increases each year. In the next figure, the scope of the three project subjects is displayed under the LIPS project cycle representation [3]:

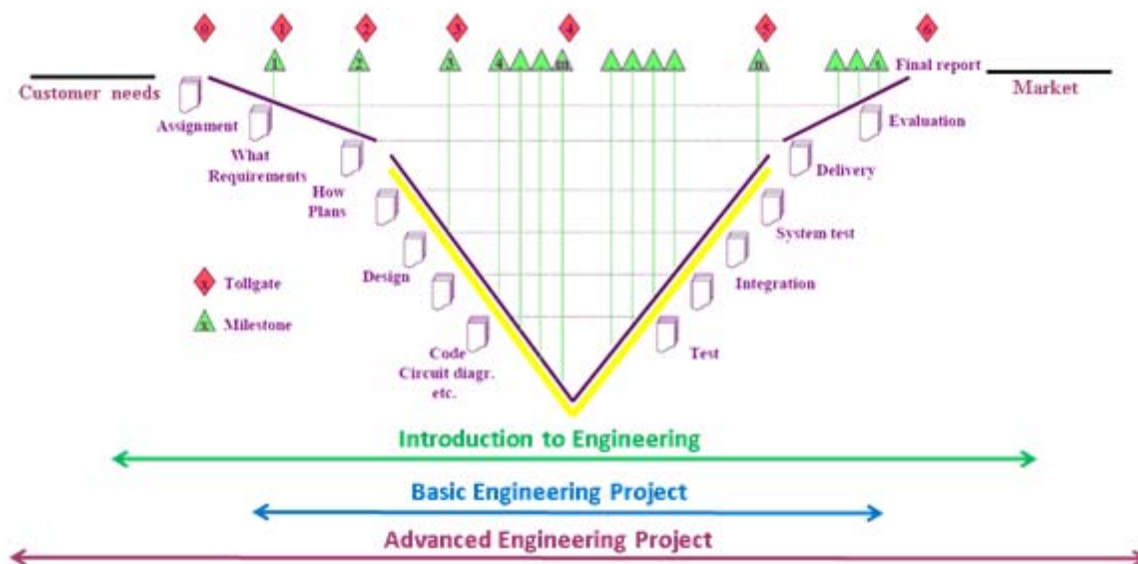


Figure 1. Scope of the three first design-build subject projects represented below the LIPS project cycle representation (adapted from [3]).

The project included in the Introduction to Engineering subject is partially guided and has low complexity, but has a broad scope, given that the students start from a system-level client specifications, they design parts of the system, build the whole system and should define a business idea based on a similar device. On the other hand, the second year project (Basic Engineering Project) has a higher technical difficulty and emphasizes the modular structure of complex ICT systems, although a work team will only develop one of the system blocks. The product is defined by the client (faculties) and also the block breakdown is given. The student teams should design and implement only a given block from specifications but knowing the whole system structure and the interfaces between blocks. The final result is delivered to the company internal client (again the faculties). In the third year project (Advanced Engineering Project), larger work groups would develop a whole system, including its business plan. They should conceive the product, define the project breakdown structure and work packages, distribute them between the sub-teams, design and implement the sub-systems, integrate them and define a business plan based on the product. That is, to take the broad scope of the first project together with the depth of the second and the business and management concepts learnt in a specific subject which is located in the first half of the third year. The Advanced Engineering Project subject has not yet been implemented. It will be done in the second half of the 2011-2012 academic year.

THE BASIC ENGINEERING PROJECT SUBJECT

Course structure

Two of the six ECTS credits are used to learn the contents and practical aspects on the regulation of telecommunications, which is required for the professional ICT engineering practitioners in Spain. The Basic Engineering Project is performed in the remaining 4 ECTS

credits (3 hours/week in the lab + 4 hours/week of autonomous work). It can be argued that a reasonable way to arrange this double function of the subject would have been to include the regulatory aspects in the projects. This is true, but this solution drives to the need of performing strict telecommunication facilities projects with all students, while the adopted solution allows us to choose a wider range of topics. With the selected way, if a given set of students choose an advanced project on telecom facilities, they would learn more about regulatory contents, but all students have received the minimum mandatory training.

There is a constraint due to the structure of our curricula: the students of electrical engineering are attending their second year, which is common to all of them, but they are going to split in four majors in the third year: electronics, audiovisual systems, networks and telecommunication systems (there is an additional degree, which has a wider scope, Telecom Science and Technology). Then, the students' interests can be slightly different. A whole system would include aspects from all these specialities, but not a given block. Then, there is a trade-off between the depth and breadth of the design given the limited time schedule (4 ECTS credits). To solve this compromise, we have designed a course structure where the students will be allowed to choose which part of the system would develop. A given system (figure 2) is divided in four blocks including aspects of hardware development, communications, network protocols and audio/image/video signal processing. Given that the second year students are mixed in class groups, we should give simultaneous labs with support of lecturers from different departments (figure 3)

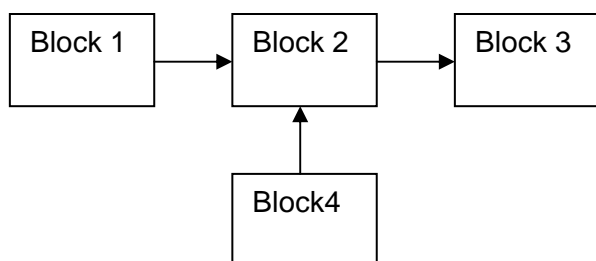


Figure 2: System block diagram

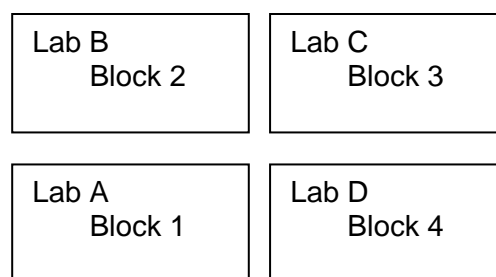


Figure 3: Simultaneous labs structure

Students can be grouped together to make the project according to their specialty although they are mixed up in class. Two class groups (60-80 students) would give enough diversity to fill the four sub-projects. Variations in the technology used to implement each block can drive to different projects built around an initial proposal, which allows amortizing the effort made by the faculties when designing the case study and use it along 2-4 semesters.

Course goals and learning outcomes

Course goals:

- Consolidation and improvement of the learning outcomes of previous and simultaneous courses
- Enhancement of the CDIO skills at medium level (mainly Design and Implementation)
- Acquisition of generic skills at medium level (see table 2)

Learning outcomes:

- Project management and documentation skills
- Specific disciplinary knowledge about the project topic
- Practical design and implementation skills
 - System and circuit level simulation and characterization
 - Measurement strategies
 - Electronic components selection and circuit building
- Generic skills learning outcomes (assigned and defined in the degree syllabus)

Table 2
Generic skills (medium level) stressed and assessed in this course

#	Generic Skill	Exposed	Stressed	Assessed
1	Innovation and entrepreneurship	X	X	X
2	Societal and environmental context	X	X	X
3	Communication in a foreign language (English)	X	X	
4	Oral and written communication	X	X	X
5	Teamwork	X	X	
6	Survey of information resources	X	X	
7	Autonomous learning	X		
8	Ability to identify, formulate and solve engineering problems	X		
9	Ability to Conceive, Design, Implement and Operate complex systems in the ICT context	X	X	X
10	Experimental behaviour and ability to manage instruments	X	X	

Course design

The students are grouped in teams of 4-6 (depending on the project complexity) and sign a team constitution agreement in which they define their role and commit to have a common ambition of reaching a given mark (pass, good, outstanding). A major concern we have had in the course design is the interpretation and application of the PBL methods to the course design. Leaving apart the classical concept of the “project subject” in the Spanish Engineering Schools, centred in the formal aspects (documentation, budget, ...) and not in creativity and design, the current trends (at least in Spain) are emphasizing the capability of PBL to improve the disciplinary contents learning instead of providing authentic engineering experiences. Of course, any implementation of PBL is better for the learning of skills than a classical expository course approach but, if a project subject is substituting a given disciplinary subject, the need of providing disciplinary contents drives to the use of contents-oriented methods (puzzles, lectures) which are a bit artificial in a real engineering context. On the other hand, these methods provide ways to assess the individual task of the students which are valuable. In our case, the project subjects are not substituting the disciplinary subjects but supporting them. Looking for a trade-off, we have limited to the first three sessions the disciplinary contents upgrading activities and left the remaining 10 sessions for design-build activities. The generic course schedule is shown in the following table. In the Course Implementation section, more details can be found over the example implemented this year.

Table 3
Generic course schedule

Week	Activity	Deliverables
1	- Course introduction - Brainstroming about the product structure and specs. - Puzzle assignment	
2-3	- Puzzle activities about disciplinary contents referred to the project - Block requirements definition	1-2 pages report + 2 slides on each puzzle topic
4	- 3d puzzle about block implementation alternatives - Brainstroming about tasks and work packages planning	Requirement Specification document
5 -8	- Block design and prototyping	Project Plan document Prototype characterization
9-12	- Block improvement and finishing	Second prototype design
13	- Final project presentation	Project final report

The documentation has been adapted from the LIPS standard [3]. We started using the LIPS documents in the Introduction to Engineering subject project as they are. After two semesters, we find them a bit complex for small projects and we have simplified the structure of the documents, which are limited to: Requirement Specification, Project Plan, Progress Reports and Final Report.

Course assessment

The initial individual assignments have a small weight in the mark but it is mandatory to deliver them on time. There is a strong penalty (20% per delayed delivery) if less than 80% are delivered on time. Another 20% of the mark is obtained from individual tests about the project contents. The remaining 60% of the mark is assigned to the whole team performance, but there is a 10% which comes from the coherence in the individual marks of the team members, to promote the individual effort. The assessment of the deliverables is based on rubrics which try to take into account both the results and the procedures employed by the students.

- Puzzle and project individual assignments.....20%
(20% penalty in the whole mark if less than 80% on time)
- Project60%
 - 20% half course performance
 - 30% final performance
 - 10% group coherence
- Project contents individual tests (2).....20%

Course implementation

This year, the chosen topic is the design of a component of an in-home audio system, an active loudspeaker able to be powered from the mains AC supply and which would play sound coming from a digital source transmitted wirelessly (figure 4).



Figure 4: Product definition: In-home audio system with wireless digital data streaming

The system blocks are: a) signal codification-decodification and streaming, b) transmission (wifi/zigbee/plc), c) amplification and d) digital equalization.

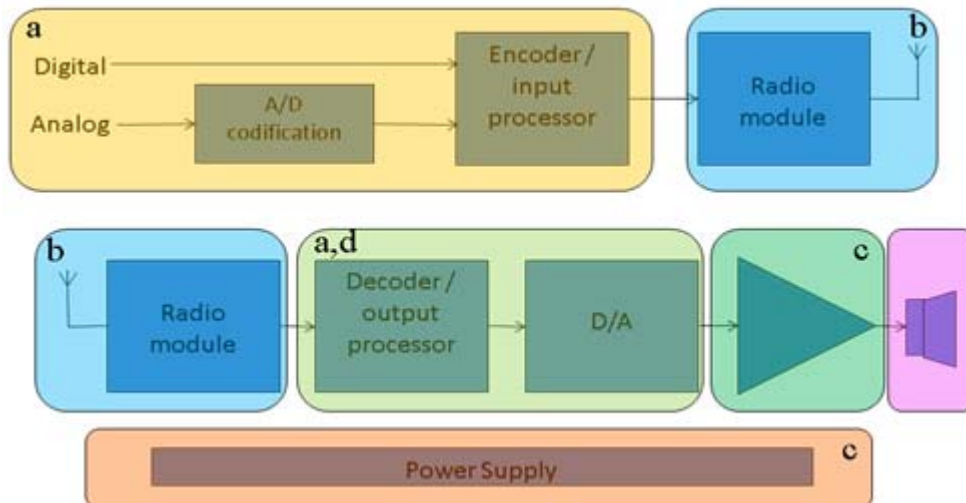


Figure 5: Product block structure and grouping of blocks in sub-projects

This first year of implementation we are running with a small pilot group of 24 students from electronic engineering and audiovisual systems engineering. Because of this, the system structure and blocks a) and b) are provided by the faculties. The students should design and build the amplifier, characterize it and also the amplifier-loudspeaker set behaviour and pre-equalize the whole response using Matlab. They have a restriction in cost and in power efficiency (>80%) so they are compelled to choose a D-class switched amplifier structure. Although this amplifier admits a complex implementation and analysis, it can also be understood by sophomore students [4]. The students have completed or are studying two courses on electronic circuits, signal processing and networks. They can only use the basic circuit blocks they know: operational amplifiers, comparators, transistors and filters. The design and implementation includes the following tasks:

- choosing the topology
- designing its main parameters
- simulating its behavioral model
- implementing the circuit blocks
- characterizing them separately and put together
- designing and building the printed circuit board
- characterizing the amplifier-loudspeaker set
- designing the digital equalizer
- characterizing the whole set
- side aspects: selecting a power supply, taking care of electromagnetic interferences.

The first day, after the course introduction, a brainstorming about the product structure and specifications was conducted. Then, the product block breakdown and interface properties were presented by the faculties and the assignment for this year (amplifier + pre-equalization) was established. The first sessions puzzles have been about audio amplifier structures: the topics have been split in four packages and prepared each one by one of the group members. The first puzzle (second day) was about audio amplifier classes: A, B, A-B, D. The second day, after the experts meeting and the presentation to the group partners, a brainstorming was conducted to extract the conclusions and to drive to the need of choosing a class-D structure after specifying a power efficiency higher than 80%. The second puzzle topics were: Class-D topologies, signal spectrum, output stages and output filters. After the second puzzle activities, the third day, a third brainstorming about pros and cons of the design alternatives was conducted. A third puzzle-like activity was proposed to give individual assignments for the preparation of the Matlab scripts that would be used to perform the behavioural simulation of the amplifier structure. At this point, the assignment for each group was clear and they could prepare the Requirement Specification document with their own interpretation

of the given specification. This document includes a background section which is filled by joining and integrating the documents prepared to fulfil the puzzle assignments. Once validated the Requirement Specification, the groups are asked to present the project Plan Document, which includes a Time Plan and a Work Package description. The remaining project weeks, the groups are supposed to follow this plan and are checked at two points: the Preliminary Design Review (PDR), at week 7, when the first prototype should be working and the Critical Design Review (CDR), at week 11, when there is no return in the chosen alternatives and the second prototype should be working, including the pre-equalisation, and only finishing and improving activities should be running. Figure 6 shows the V diagram of the project and table 3 the tollgates. The V diagram shows two parallel groups of tasks because, additionally to the amplifier circuit, they should design two Matlab based virtual instruments (frequency response analyser and audio spectrum analyser + THD measurer)

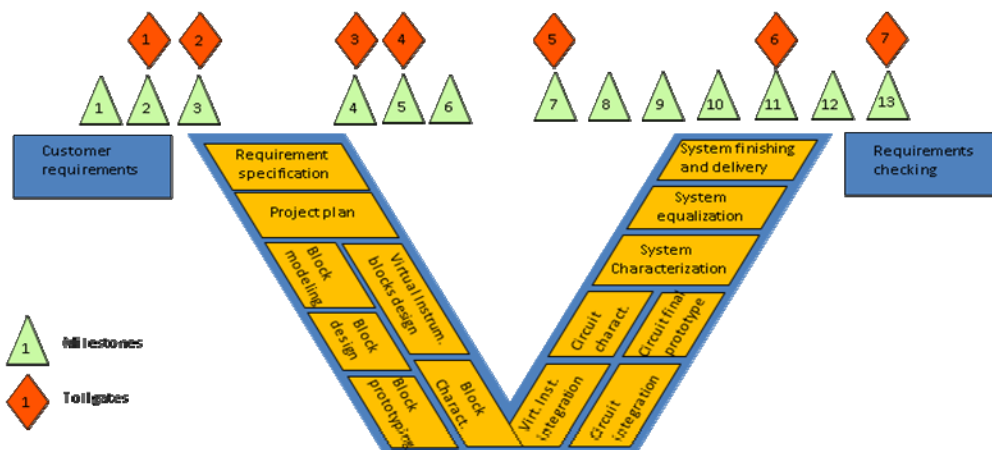


Figure 6: V diagram of the project. While the tollgates are determined by the faculties, the weekly milestones are internal decisions of the groups, according to their project plan.

Table 3
Project tollgates and the corresponding deliverables

#	week	Deliverables
1	2	Puzzle 1
2	3	Puzzle 2
3	4	Blocks models, requirement specification, timeplan proposal
4	5	Project plan
5	7	First prototype evaluation. Progress meeting 1. PDR
6	11	Preequalizer . Progress meeting 2. CDR
7	14	Final results presentation

The next academic year enough students will be enrolled in that course to perform the simultaneous design of all the different blocks of a complex system in different laboratory groups. In the second year project, the students work in depth in the design of a block of a complex system and acquire skills to face the design of a complete complex system in the third year project. The pilot group will reach this project in the next academic year.

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A DESIGN BUILD ACTIVITY FOR A “DESIGN BUILD” COURSE

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ABSTRACT

This paper deals with the CDIO course “Design Build”, which is taught in the first semester of the Bachelor of Engineering education at the Technical University of Denmark’s Department of Civil Engineering. A specific design build assignment has been developed for the course, and the paper describes this course activity. The “Design Build” course revolves around the activity that the students should build a model house of their own during the course. The only demands stipulated are that the house should be made as a scale 1:20 model of a realistic house and that it should be thermally insulated and tight. The students work together in groups of four. As part of the CDIO process, each group of students should work through a conceptualization phase, where the requirements for the house are defined. Then follows the phase where the house is designed as the best possible solution fulfilling the requirements the students had set. Next, for implementation, the model house is constructed in the workshop, and the measuring system is tested and installed in the house. Finally, the house will be operated by putting it on the ground in an outdoor test field where it is exposed to the Danish climate for two weeks while the indoor temperature and heat consumption are logged. The experimental findings shall be compared to a theoretical value for the heat loss, which is found from a calculation method the students learn in a parallel course. While the course has resulted in a lot of enthusiasm among the students towards the specific construction task, it has also led to some initial frustration that the course content was not given as a well described assignment, and that the course curriculum had to be to some extent self-defined. This has been a challenge to the very young students who have participated in the course.

KEYWORDS

Design Build course, constructing, experiments, field test, group work, team building, theoretical assessment.

INTRODUCTION

The CDIO concept was introduced in 2008 at the Technical University of Denmark (DTU) as a general teaching paradigm for all students in the first two years of the university's Bachelor of Engineering program. The main goal set for starting the CDIO concept was to work on the process of reforming the B.Sc. courses with the purpose of training students to become better and more efficient engineers.

The design build activities in several educations at DTU have been described by Vigild et al [1]. The DTU model [2] includes within the first four semesters two design build projects and two other interdisciplinary projects. The 1st and 4th semester design build projects were described and evaluated by Christensen et al [3] and by Krogsbøll et al [4]. An overview of the CDIO projects in civil engineering study program at DTU is described by Krogsbøll et al [5] and the connections to teaching interpersonal skills by Christensen et al [6]. The study program for civil engineering students for the 1st semester is shown in Figure 1.

	13 weeks semester					3 weeks
	5 ECTS	5 ECTS	5 ECTS	5 ECTS	5 ECTS	5 ECTS
1	Mathematics 1	Mechanics 1	Physics	Design within building energy	Design build 1. Small house	AutoCAD

Figure 1. Study program for civil engineering students for the 1th semester [5].

The structure for the courses at DTU is with two semesters each year – either fall or spring. Each semester consists of a 13-week period prescribed for courses of a total of 25 ECTS points (European Credit Transfer and Accumulation System), a two-week exam period and a three-week period prescribed for a 5 ECTS points course, which is usually a more practical course with parts of the theory from the 13- week period put into practice. The students are supposed to earn a total of 30 ECTS points during a semester.

This paper describes the activity in a 5 ECTS point “Design Build” course, which is to be taken in the first semester at the Department of Civil Engineering, where CDIO is introduced. The course is in the 13-week period and can be in the fall or spring.

DESIGN BUILD COURSE, 1st SEMESTER – THE ASSIGNMENT

At startup, there was no method or already existing example how to teach building engineering according to the CDIO concepts. It was required to develop a design-build course for first semester students from scratch. This evolved as a brain storm process among the faculty in the CDIO planning committee. The new course should link to one of the theoretical courses, which was in the curriculum of the B.Eng. students' first year of study. This developed into the idea that the students should be given the assignment of designing, construction and testing a small model house, and for theoretical companionship, they should have focus on the aspects of heating such a house, and be able to calculate the heating requirement.

The following assignment was developed:

Conceive

The students are asked to reflect on why we live in or go to work in buildings. What kind of shelter do they constitute, and which performance requirements need be fulfilled by buildings?

The students are presented with the term “building envelope”, which in Danish translates as “klimaskærm”, or “climatic shelter”. Issues such as: protection against rain penetration, wind-tightness, thermal insulation, access to daylight, protection against burglars, being economical, visual appearance, etc. are among the themes that typically come up. When listing the performance requirements, the students shall reflect on which materials and configurations can provide the necessary functions, see Figure 2.



Figure 2. Students in the conception face pondering over the requirements from a house.

The students are not presented with any textbooks or notes for the conception phase. Instead they see a brief power point show that sparks interest in some arbitrary reasons why we live in buildings, and the students are referred to the fact that they already live in a building, and are used to going to school in one. In addition, they are invited to go on the Internet to harvest information about why and how we build. Already on the first day, the students are left with thinking of some of these issues, and they present their initial thoughts to one another on the first day. Before coming to the second lecture they should describe their home to one of their new class mates, and at the next lecture, the class mate will explain how their buildings is. This is in order to train the students to use their a priori knowledge of a vocabulary for buildings to express their thoughts.

During this phase, the students are put in group of four students with whom they should work for the rest of the course.

Design

In the second phase (after a couple of weeks), the students are asked to begin designing the buildings they will produce during the course. The building should be a model of a single family detached house in scale 1:20, replicating a house which in reality would be some 150m².

The students are given some basic instructions in drawing, and they come on an excursion to a construction site. It is now up to the students to discuss in their groups how should be the design of their building. They should present some alternatives, and they should express which functions the designs solve. Most important is perhaps that the students are asked to document their designs with whatever means they have learned in the drawing lessons or by means they can think of themselves. Handmade drawings, computer drawings, e.g. with SketchUp, PowerPoint shows, and textual descriptions come into play, see Figure 3.

By the end of the Design phase, after approximately some 4 weeks, the students should deliver the documentation after which they can later construct the model houses. By that time

they will also have decided which materials should be used, and they deliver an order list to the teaching assistant who will then within reasonable judgement procure the materials for the students.

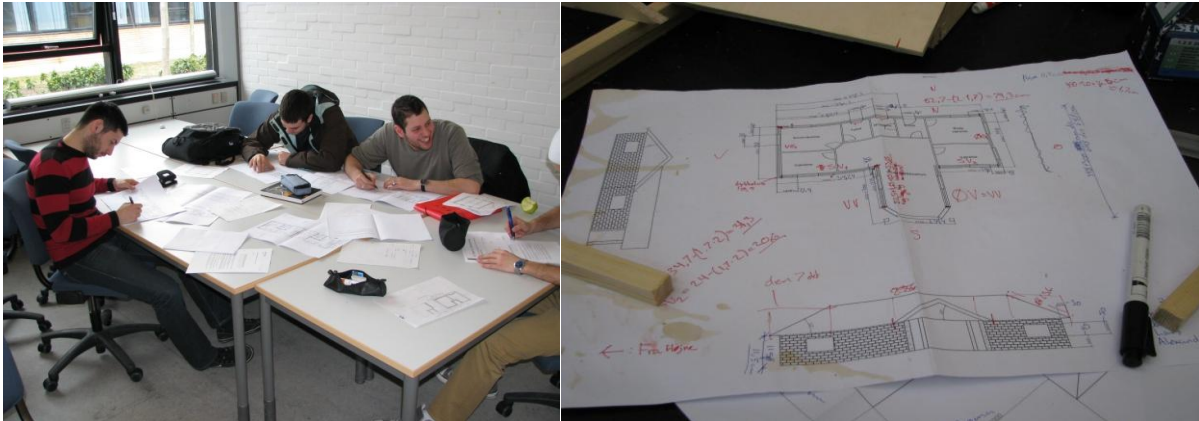


Figure 3. Students in the design face, where they design the house.

At this moment, the students have also advanced enough in the companion theoretical course, that they are now able to calculate the specific heat loss (in units W/K) of their model building by adopting the calculation rules that apply to normal buildings. These calculations are delivered along with the documentation of their design, and form a mid-term deliverable from the students. The students also present their projects to everyone in the class.

Implement

The implementation phase is predominantly an activity in the workshop. Each group of students is given a 10x60x90 cm board of Expanded Polystyrene which will form the base on which they can build their house, see Figure 4.



Figure 4. Students in the implementing face, where they built the house.

They are also given a board upon which is mounted a heating unit in the form of an 18 Ohm power resistance, an adjustable thermostatic switch, and a small fan to circulate air. The house is to be built around the control board, and on top of the polystyrene. The board comes with a wire to supply power at 24 V DC, and it has some screws on which a HOBO data logger can be docked, see Figure 5.



Figure 5. In the implementing face, the students have mounted a heating unit, an adjustable thermostatic switch, and a small fan to circulate air.

Apart from constructing the model house during the implementing period, the students also have to get accustomed with the HOBO-logger that each group is provided with, and to understand the basics of supplying and measuring the electric heating power that is delivered to the house. In addition to the power, the HOBO logger also measures the temperature at the control board in the model house. The students are instructed to learn the operation of these devices to such certainty that no mistakes are made in the subsequent operation phase. In that last phase they simply need to have some results in order to be able to write their final report.

The implementing phase takes around 3 weeks.

Operate

In the operating phase, the model buildings are taken outside to be tested for exposure to the real outdoor climate. We are now either in November or April. The houses are connected to the power, and thus heated to the set temperature which is being logged along with the voltage supplied to the power resistance. Together with the rated power of the small fans that circulate the air in the small building, the students can determine in 3 minute intervals the amount of heat supplied to the building. The outdoor temperature at the test site is measured at the same time. In spring, when it may get warm outdoors, the students are advised to put the set indoor temperature high so as to be sure there will be a heat loss from the building.

The model houses are tested for at least two weeks, during which time at least one alteration of the test conditions should be attempted, e.g. by turning the house so the solar gain through the windows may be different, or by making some notable (yet easy to implement) changes to the design, see Figure 6.

After the test period, it is up to the students to draw and analyze the data from the data loggers and to process them in such a way that temporal or long term average specific heat losses can be deduced. These results should come in the final report, where they are compared to the theoretical values that were determined by the end of the design phase. Most often, there are deviations between the theoretical and experimentally found specific heat losses, and the students are encouraged to comment and possibly explain such deviations.



Figure 6. The operating phase, where the students test the houses outdoors – left. The houses are connected to the electrical power – right.

The reports which are handed in are graded on the Danish 7-scale.

ASSESSMENT

For the last 14 years, the students at DTU have evaluated the courses they have attended. For the last 9 years this has been done electronically as an integrated part of the CampusNet computing and course administration system. The electronic evaluation system at DTU has been described in a former paper at the 1st CDIO conference [7]. By introducing the electronic evaluation system on the university's CampusNet, there has been opened for a detailed assessment of the evaluation data, which makes it possible to extract important information. However the negative side effect is that the students get tired of the evaluation questions of all their courses. Six courses each semester make it up to 12 evaluation questionnaires to fill in every year. The response rate varies a lot from course to course, and in many cases the response rate is rather low, which means it will not be representative.

In an investigation by Christensen et al. [3] of the Design Build course there was focus on achieving as high a response rate as possible, close to 100%, for the students attending a special teaching day where the students presented their work. The paper inquiry forms were handed out to the students, and they were asked to fill it out right away, and after having done so the forms were collected. The result from this was a 100% response rate of the students that were attending this obligatory presentation.

The paper questionnaire was drawn up as a two-page inquiry form with 16 questions on the front page and possibilities for individual comments on the reverse side of the page. The answers were ranked from very good (positive) (5) to very bad (negative) (1) to simplify the students' answers and to make it possible to quantify them.

In the following is an interpretation of some of the questions of the questionnaires from [3] will be described.

1. *“To what extent did this course make you conscious of the process from conceiving an idea to the implementation?”* – see results in Figure 7. The philosophy behind the concept of CDIO is to make the C, D, I and O visible and form part of the teaching frame progress. The teaching has to show a picture and authentic elements have to be brought into the teaching in the CDIO Design Build course. In the first question, where the students have been asked: to what extent did this course make you conscious of the process from conceiving an idea to the implementation? – 62% gave the score 4 or 5, 30% average 3. Only 8% gave the low

score 2 and 0% the lowest score very bad – 1. The results from this question show that the course seen from a CDIO point of view has been a great success since 92% gave from medium to the highest score.

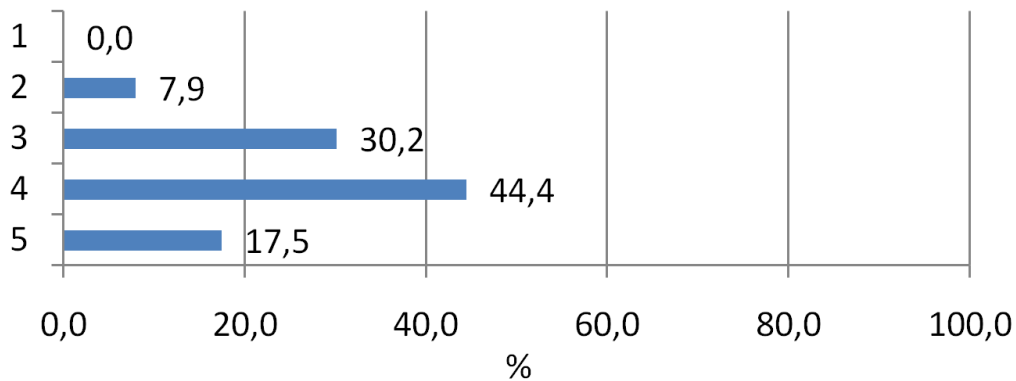


Figure 7. Results from Question 1 – “To what extent did this course make you conscious of the process from conceiving an idea to the implementation?”. The scores are ranked from very good (positive) (5) to very bad (negative) (1).

3. “Did the lessons/project make you commit yourself?”, Figure 8 – 75% gave the score 4 or 5, 20% the average score 3. Only 5% gave the low score 2, and 0 % the lowest score very bad – 1. From this it can be seen that 95% of the students find themselves committed to the project by giving the score from medium to high. This shows that the CDIO concept commits the students in the engineering education but also that the students who are maybe not so book-learned but rather prefers practical education can use the CDIO concept.

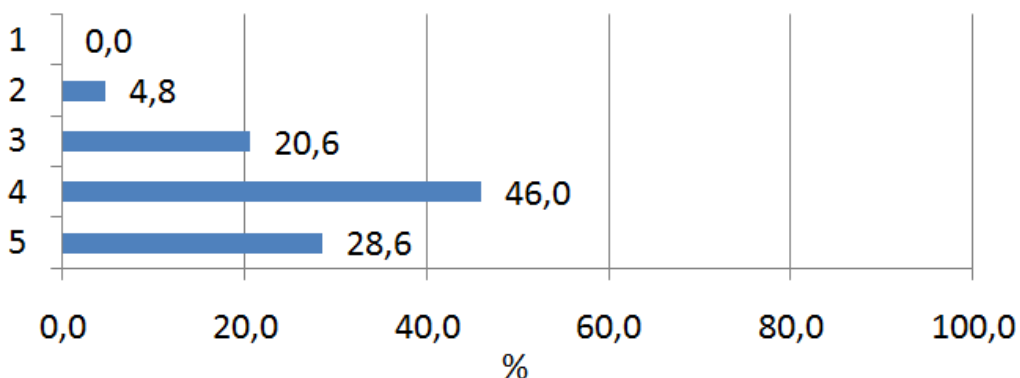


Figure 8. Results from Question 3 – “Did the lessons/project make you commit yourself?”. The scores are ranked from very good (positive) (5) to very bad (negative) (1).

4. “Did the teaching method of this course motivate you for added interest in studying constructional engineering?”, Figure 9. The concept of CDIO is to integrate and involve the students in the teaching process and make them more interested in the study. The scores show that the CDIO concept used in the course has been a success in respect to making the students interested in studying to become an engineer, since 74% of the students gave the score 4 or 5, 20% average 3 and only 5% gave the low score 2 and 0 % the lowest score very bad.

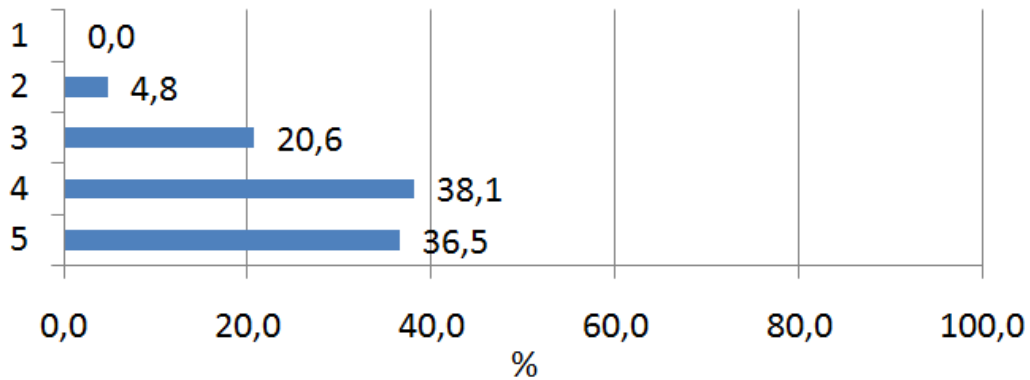


Figure 9. Results from Question 4 – “Did the teaching method of this course motivate you for added interest in studying constructional engineering?”. The scores are ranked from very good (positive) (5) to very bad (negative) (1).

10. “Do you experience that the course gives you a wide introduction to engineering and studies of constructional engineering?”, Figure 10 – 29% gave score 3, 44% – score 4 and 14% the highest score 5. Altogether adding up to 87% giving a score from 3 to 5 shows a high satisfaction. This can be an important issue for the students’ decision concerning whether to continue their study to become an engineer or to change study. The answer also indicates that the CDIO course is a good alternative to the traditional teaching.

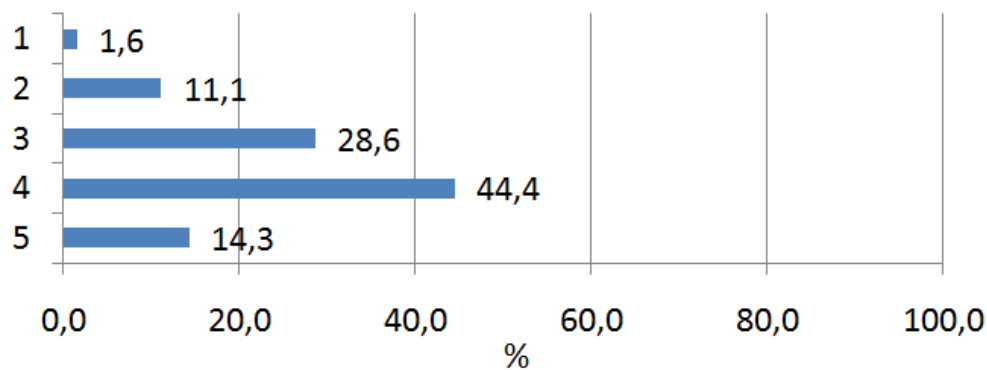


Figure 10. Results from Question 10 – “Do you experience that the course gives you a wide introduction to engineering and studies of constructional engineering?”. The scores are ranked from very good (positive) (5) to very bad (negative) (1).

Altogether, these four questions dealing with the “Design Build” course show a very high contentment with the course and the interactive education with personal involvement in the CDIO faces. The positive answers indicate that the students did improve on engineering skills. The students are very satisfied with the course and they recognise the idea of the contents of the course. However it has been pointed out by one student [6]: “Especially in the process of getting to know your new fellow students, there is a lack of courses at DTU that can support these areas.” Since this is a first semester course, where the student don’t know there fellow students, it could be a good idea to improve the course by including an icebreaking part in the beginning of the course.

CONCLUSION

This paper describes an example of the implementation of CDIO as a “Design Build” course and how it has been taught in the first semester of the Bachelor of Engineering education at the Technical University of Denmark. The students express satisfaction with working together in groups in order to solve the task. In general according to the investigation by Christensen et al. [3] the results show a very high gratification with the Design Build course, and the

students like the practical approach in the CDIO concept. The students are very committed and the course motivates them for an added interest in studying building engineering. In addition the course is a good alternative to the traditional technical courses [3]. However, some challenges still remain with the course: Some students feel somewhat intimidated that they have to find out so many things themselves. Based on the feedback from the students the course has been continuously improved since the start.

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CONSTRUCTIVE ALIGNMENT (CA) FOR DEGREE PROJECTS – INTENDED LEARNING OUTCOMES, TEACHING & ASSESSMENT

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ABSTRACT

Degree projects (DP) are currently intensively focused in Sweden: The future national model for evaluation of higher education will place a major emphasis on the quality of degree projects as an indicator of the quality of the entire education, and their quality will influence the funding of a university. Moreover, DP:s are actively used in program development as a vehicle to develop not only in-depth subject matter knowledge but also professional skills such as planning and communication. Simultaneously, Constructive alignment (CA) is being widely applied as a general approach for improving educational quality. Potentially, CA might also contribute to improving the quality of degree projects. In this paper, we examine how CA can be applied to degree projects. We conclude that CA is indeed applicable to degree projects in the sense that intended learning outcomes as well as teaching and assessment activities can be identified and aligned. But objectives, activities and assessment are less crisp than for a course, and the perspective of objectives or criteria found in the current investigation tends to be suitable for a program manager rather than an individual teacher. If CA is to provide a similar “aha” experience for a teacher as it can do when applied to a course, the intended learning outcomes need to be specialized for the particular degree project. We further identify areas where CA for degree projects can contribute to higher quality, including: supporting the planning of professional skills development in degree projects, guiding a dialogue between teacher and student on what constitutes high/low quality of a thesis, and encouraging students to take more responsibility for their learning, by forcing them to develop contextualized learning outcomes for their project.

KEYWORDS

Degree project, Constructive alignment, Education quality, Integrated learning

INTRODUCTION

Degree projects (DP) are currently intensively focused in Sweden: The future national model for evaluation of higher education will place a major emphasis on the quality of degree project as an indicator of the quality of the entire education, and degree project report quality will influence the funding of a university [1]. Moreover, DP's are becoming actively used in program development as a vehicle to demonstrate not only in-depth subject matter knowledge but also professional skills such as planning and communication. In addition,

university rules regarding the obligations of the examiner as well as the student and also criteria for assessment are being introduced. Today, however, degree projects are tutored and examined by practice developed by supervisors as individuals accompanied by common practice at departments. The discussion of what constitutes good intended learning outcomes of a DP, of what constitutes a good thesis, and of what constitutes good teaching in DP:s is still in an early phase.

Simultaneously, Constructive alignment (CA) [2], [3] is widely being applied as a general approach for improving the education quality. For example, Chalmers University of Technology (Chalmers) has started a project to assure that all of its courses are constructively aligned, including project courses. Project work have since long been a part of Swedish engineering education. During the last ten years or so, the special challenges for teaching project courses have been more acknowledged especially since the CDIO based engineering education started to gain support. Within the CDIO community three universities took part in an investigation to highlight difficulties as well as good examples to promote learning during projects [9]. Several of the issues are shared with degree projects, e.g. separating between project success and student learning during the project or integration of generic skills. Based on the above, potentially CA might also contribute to improving the quality of degree projects.

The aim of this paper is therefore to discuss the applicability of CA to degree projects and possibilities of CA to enhance quality of DP:s. Specifically, we investigate guidelines regarding degree projects in a national perspective as well as current practice at Chalmers in setting goals for, teaching and assessing degree projects.

The remainder of the paper is organized as follows: We start by reviewing the fundamentals of constructive alignment, discussing some related work in the area and outlining our research questions and research approach. We then discuss some specific characteristics of degree projects, and identify some aspects that are challenging from a CA perspective. In the analysis part of the paper we examine degree projects in relation to the three main CA components: the intended learning outcomes, the teaching and learning activities, and the assessment formats and criteria. Specific details and examples are taken from the Swedish and Chalmers context. We address the research questions in the discussion section and wrap up the paper by some concluding remarks.

CONSTRUCTIVE ALIGNMENT

The framework of constructive alignment was developed by Biggs [2], [3]. It stands on two basic pillars. It is founded both on a view on student learning (“constructive”) and a principle for designing “good” educational events, ranging from lessons to courses to programs (“alignment”).

Biggs view on student learning is inspired by constructivism. Learners are said to ‘construct’ knowledge by their own activities, building on what they already know. Constructivism is argued to be a helpful tool for thinking about teaching as it emphasizes what students have to do to construct knowledge. Biggs further argues that if learning of significant depth is to happen, certain basic conditions need to be met: There should be clear goals for the activity. The students should perceive these goals as meaningful. The assessment should appropriately test the fulfilment of the goals, and there should be student-teacher atmosphere characterised by an open dialogue.

The second word, “alignment” refers to the design of the educational event. The design of an educational event comprises its intended learning outcomes (ILO), the teaching and learning activities and the assessment task. The design is “aligned” if the ILO:s are clear and relevant, if the teaching and learning activities make it possible for the students to acquire the

knowledge and skills defined by the ILO:s and if the assessment tasks provide a purposeful test that the students has mastered the ILO:s. Figure 1 summarises the main components of the CA framework.

The framework has been applied in many educational domains, including veterinary science, accounting and management science [3]. Problem based learning (PBL) lends itself very naturally to CA and thus a number of publications here at Chalmers have treated teaching, learning and assessment in project courses in engineering education where CA is explicitly or implicitly used to plan the courses. Evertsson et al. [5] show how they systematically align and assess detailed ILO for the second year Design-Build-Test (DBT) project course Integrated Design and Manufacturing. Bachelor thesis projects at Chalmers have been subject to constructive alignment [6]. Finally, Andersson et al. [7] present a systematic approach to identify learning objectives, teaching efforts and assessment for Chalmers Formula Student DBT project which started as a extracurricular project but evolved into a course on advanced master level.

Degree projects can be seen as a special kind of project course. Biggs ([3], pp 226-227) discusses capstone/final year projects and points out that they are especially useful in assessing skills that according to Biggs cannot be directly taught, including creativity and life-long learning. However, Biggs does not discuss degree projects in depth. Thus, this paper contributes a more in-depth analysis of the specific characteristics of degree projects, coupled to an assessment of to what extent CA is helpful in designing, teaching and assessing degree projects.

Specifically, we examine the following research questions in the paper:

- To what extent is CA applicable for degree projects?
- How can the “aha” experience of working with CA for your own course be experienced by Degree project examiners/teachers?
- How can CA for degree projects contribute to higher quality? Why/why not?

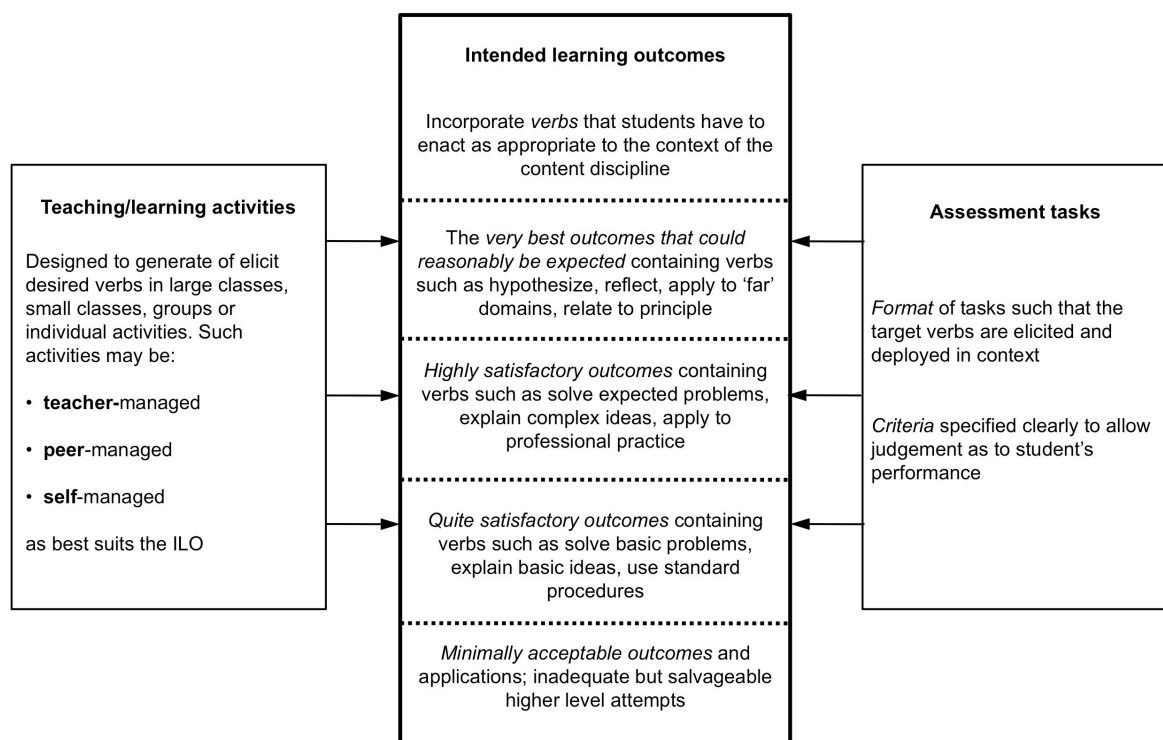


Figure 1. Aligning ILO:s, teaching and assessment tasks [3].

RESEARCH APPROACH

The findings in this paper are derived from analysis of documents and interviews. The documentation was mainly regulations and guidelines for intended learning outcomes and assessment of degree projects from the Swedish government and from Swedish universities. The interview material is based on twelve semi-structured interviews with faculty from three different departments at Chalmers University of Technology. The interviews lasted 30-60 minutes, were transcribed and coded. Some quantitative data was available through Chalmers alumni surveys. We also had access to notes from some additional faculty interviews done by another researcher [8]. Preliminary findings have been validated in two workshops for faculty.

DEGREE PROJECTS – SOME BASIC CHARACTERISTICS AND PEDAGOGIC CHALLENGES

Degree projects (final year projects, independent work) are projects that are placed last in the education. Their aim is to serve as a learning experience that integrates the disciplinary knowledge that the student has learned over the course of the education with the professional skills needed to make use of the knowledge in practice.

The Swedish education system places a high importance on the degree project:

“The government considers the independent work (degree project) as central for confirming that the student has fulfilled the requirements for the degree. In the independent work, the student shows that he or she does not only have amassed factual knowledge, but also can apply and further develop this knowledge with the level of independence that is required to practise the profession that the education prepares for, or for entering a more advanced level of studies” [9].

In Swedish engineering education, degree projects range from 15 ECTS (BScEng) to 30 or 60 (MScEng). It is thus typically the largest single learning experience of the curriculum. Degree projects are done by a single student, or by two in collaboration. Students may have done many projects earlier in the education, but the degree project should stand out by being a significantly larger and more difficult task, and by requiring more independence from the student.

One challenging aspect of degree projects is due to that many engineering degree projects are done in industry. At Chalmers University of Technology, about 2/3 of the MScEng degree projects are done in industry [10]. This is essential as it enables the student to apply his/her knowledge on a “real” problem, strengthening learning and motivation. However, it may also limit the teacher’s ability to influence the goals of the project and parts of the teaching in the project will be performed by an industrial supervisor with limited knowledge of and engagement in the university’s goals for a degree project. The degree project task is thus often stated by someone other than the teacher, resulting in a significant variation in tasks that should be taught towards the same intended learning outcomes. As an illustration, Table 1 lists a few recent MScEng degree projects supervised by the paper authors. It is evident that the task variation is significant.

The industry contacts acquired through an industry degree project may also be an in-road to a future employment. However, this may also lead that the degree project is viewed as an internship, a test employment or from the company’s perspective even cheap consultant hours. On the other hand, degree projects conducted in academic settings, may have as an explicit goal to produce an academic publication, pushing the engineering application element to the background. Both such tendencies can strengthen the conflict between learning and project goals that is a known challenge in project courses, e.g, [11].

Another view of degree projects is to consider them as large exams, where the student demonstrates that he/she can independently solve an engineering assignment of a significant complexity. In a way, this is what the governmental requirement expresses. This can lead to that university or an individual teacher adopts a relatively hands-off attitude towards the teaching efforts in degree projects: the actual teaching and learning essentially takes place before the degree project, and it is then up to the student to show that they can do the job. Nothing new is explicitly taught as part of the degree project, and there should be a minimum of “teaching” during the DP. However, degree projects may also be utilized in a more pro-active way, and be seen as vehicles for deepening subject knowledge and developing professional skills. This, however, requires carefully planned arrangements for degree projects, taking into account the inherent task variation.

Variation is thus a common word for the challenges facing a teacher in a degree project: Variation in task, variation in higher-level purpose, variation in attitude towards teaching interventions, variations in scope.

Table 1
Sample degree projects and task variation.

Title	What they spent most time on
SKF dual axis solar tracker – from concept to product	Detail design, build and test of mechanical system. CAD and FEM modeling and simulation
Premium quality at a mechanical department	Surveyed literature. Interviewed people in order to map out process and communication paths
Analysis of microstructural strain-field in grey cast irons	Literature survey, made experiments, wrote script and analysed strain-fields
Total hip replacement and dual mobility; optimized design and material for the cup	Literature survey, experiments, FEM modeling and material selection
Finite element analysis of fluid flow in fiber structures containing super-absorbents	Developed and implemented a finite element formulation. Designed and carried out experiments
Robustness and reliability of front underrun protection systems	Stochastic FE-analyses of head on collisions and statistical evaluations of responses.

LEARNING OUTCOMES FOR DEGREE PROJECTS

Let us now analyze the applicability of constructive alignment to degree projects. We start with the intended learning outcomes.

Basically, the intended learning outcomes should state what the student should be able to perform after an educational event using active cognitive verbs and verb phrases, such as describe, choose, explain, solve, apply, design, interpret, modify, sketch. The performance should be observable, that is, it must be possible to demonstrate and assess whether the outcomes have been met. In addition, activities and learning outcomes should also indicate the intended level of understanding by for instance employing taxonomy. Several proposals for such taxonomies are available. Bloom’s Taxonomy of Educational Objectives lists six levels of understanding: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation [12]. Biggs and Tang propose the levels Prestructural-Unistructural-Multistructural-Relational-Extended Abstract [3]. Feisel-Schmitz’s Technical Taxonomy identifies five levels of understanding focusing on problem solving with calculations [13]. Intended learning outcomes in e.g. a project course could preferably cover several levels of understanding and include both disciplinary knowledge as well as professional engineering skills, such as communication and project planning [14].

University-wide ILO:s

What are suitable intended learning outcomes for a degree project? If we accept the assumption that the degree project is central for demonstrating that a student masters the knowledge and skills associated with the degree, the national degree ordinance is a natural reference point. For engineering degrees, the Swedish degree ordinance lists twelve intended learning outcomes [15]. These ILO:s are listed in somewhat abbreviated form in Table 2.

One approach would be to say that any degree project should demonstrate all of these ILO:s. We can call this a “comprehensive” approach. However, there are several reasons that this is not generally feasible: Some knowledge and skills are difficult to demonstrate in a degree project done as an independent work: working in teams, for example. Moreover, the task variation amongst degree project is significant. Some projects would develop design skills, other experimental.

An alternative could be a “minimal” approach, i.e., to identify such ILO:s that are present in all degree projects. The risk is then that the learning outcomes drift farther from what the legislator explicitly states is the intention, and the university loses the opportunity to use the degree project to develop certain additional skills.

It is also an option for universities to add to the governmental requirements, i.e., by having higher ambitions in certain areas or add specific topics, such as immaterial property rights. An individual program could opt to specialize the degree requirements to the traditions of the disciplines, and require that these traditions be reflected in degree project.

Table 3 presents a comparison between ILO:s/assessment criteria for engineering and science degree projects identified at different universities and by the Swedish national agency for higher education clearly indicate that the actors differ with respect to degree project ILO:s. KTH here represents a “minimal” approach, while Chalmers ILO:s are positioned towards the comprehensive end of the spectrum. Further, specific ILO:s can be discussed: Should, for example, the process be assessed as suggested by Chalmers, KTH, LiU and Umeå? Or should broader aspects such as ethics and preparation for working life requirements be assessed as suggested by HSV? Should the oral presentation affect the student’s grade on the degree project, as done at KTH and Gothenburg University’s Faculty of Science (GU)? Even with these variations, it can be argued that the sets are primarily suited to guide and assess degree projects with a research character rather than product development character which is common in engineering education. A study done at Lund University [21] proposed two distinct sets of assessment criteria for research and product development degree projects.

Program-specific ILO:s

A university also needs to consider the generality of the degree project ILO:s: should they apply to all degrees of a certain level at the university, be department-specific or even program-specific? More general goals facilitates for students to move between departments and programs at the cost of being more abstract and lacking the flexibility for programs to introduce specific elements in the degree projects, e.g., a module on entrepreneurship. The change to the Bologna model also meant defining specific learning outcomes for the master level that a degree project should fulfil. To take a specific example; a degree project in a master program for Materials engineering can be performed at the department of Materials and manufacturing technology, but also at departments of Applied physics, Chemical and biological engineering or Applied mechanics as long as it fulfils the intended learning outcomes stated for Materials engineering.

Table 2
Abbreviated version of Swedish MScEng degree requirement ILO:s (our translation)

Knowledge and understanding	Skills and abilities	Formulation of judgements and attitudes
Knowledge of the scientific foundation of the chosen technology field, as well as insights into current research and development work	Identify, formulate and handle complex problems, and participate in research and development work	Formulate judgements considering relevant scientific, societal and ethical aspects
Broad knowledge within the chosen technology field including mathematics and science, as well as significantly deepened knowledge within certain parts of the field	Create, analyze, and critically evaluate different technical solutions	Insight into the possibilities and limitations of technology, and its role in society
	Plan, and with suitable methods carry out, qualified tasks	Identify their need for more knowledge, and to continuously develop their competence
	Integrate knowledge and model and simulate events	
	Design and develop products, processes and systems	
	Work in teams and collaborate in groups	
	Communicate in national and international context	

Contextualized ILO:s

However, also on the program level, degree projects differ with respect to, for example research or product development profile. And despite how well university-level or program-level ILO:s have been worked out, there is a fundamental limitation in the generalized character. They cannot capture the unique characteristics of every single degree project. In a sense, every degree project is similar to a unique course. University-wide or program-specific ILO:s need to be specialized to the context if they are going to be useful as guide for the learning in the project. This is a challenge but can also be used as an opportunity: the need to contextualise the ILO:s can guide a dialogue between teacher and student that ultimately encourages the student to take more responsibility for his or her learning: Exactly what knowledge of solid state physics is required? Can insights into the societal context be demonstrated in this project? What knowledge do I need to develop to meet both the project goals and the learning goals?

To summarize: ILO:s for degree project can be stated on the levels of the university, the study program or the specific project. We notice that there is variation between universities in what is considered as ILO:s for degree projects. Degree project ILO:s can thus be deliberately designed to meet certain goals of the institution. However, in order to effectively support learning in a specific degree projects, contextualized ILO:s need to be stated. From variation in ILO:s should according to the principle of constructive alignment follow variation in teaching activities and assessment.

Table 3
Comparison of ILO:s/assessment criteria for degree projects

Intended learning outcome/assessment criteria																			
Source		Engineering and science content								Process	Presentation								
KTH [16]																			
LiU/ Umeå [17]		Knowledge base	Problem statement	Results and conclusions							Written communication								
Gothenburg University [18]		Understanding	Execution	Results-analysis-interpretation					Process		Written communication	Oral communication							
Chalmers [19]		Knowledge	Method	Problem solving					Process		Written communication								
Härnqvist [20]		Research anchoring & theory awareness	Problem statement	Execution and conclusions					Method		Written communication								
HSV [21]		Knowledge and understanding	Critical thinking	Problem solving							Written communication								Preparation for working life requirements
																			Judgements with respect to societal and ethical aspects

TEACHING AND LEARNING ACTIVITIES IN DEGREE PROJECTS

From our faculty interviews it is obvious that there are many challenges in the teaching of degree projects. Some faculty have mentioned in the interviews that they have experienced pressure to take on degree projects that lie outside their field of expertise. The variety in projects inevitably challenges supervisor's knowledge. Moreover, at Chalmers we have very limited supervision training for faculty. Supervision skills are mostly self-taught by experience. It is also a fact that we have significant variation in student's pre-knowledge in supporting skills such as report writing, literature search and analysis.

It is evident that teaching and learning practices differ much. The difference depends not only on the various projects and students but also on the department or division at which the project is carried out. It is clear that the difference in teaching at different departments is coupled to different views on students' autonomy. Faculty that are linked to fundamental scientific research tend to have a more strict view on student autonomy as well as on the role as a supervisor and examiner of degree projects compared to faculty linked to more applied or engineering research. The more strict view may lead to hands-off approaches where feedback is very limited and the students need to find and build the required in-depth knowledge without any support. On the other hand, at other departments short courses in necessary theory are offered for the degree project students.

We have also noticed significant differences in teaching practices of projects in industry and projects at Chalmers. Projects at Chalmers are commonly linked to research projects and the teaching is more active and the student is often a member of the research group. Projects in industry are taught mainly by industrial supervisors and responsible supervisors act more or less as an examiners. Moreover, there are no explicit university or program level guidelines for what teaching should include in degree projects. It is done on an individual basis. However, common learning practices include:

- Personal supervision by examiner, supervisor and industrial supervisor
- Supervision meetings weekly, bi-weekly, monthly, ...
- Some general teaching – presentation skills etc
- Approval of planning report
- Instructions on how to design a thesis
- Proof-reading with feedback of the report
- Plagiarism check

ASSESSMENT OF DEGREE PROJECTS

The alignment of assessment formats and criteria with university-wide, program-wide and project-specific intended learning outcomes suggests the adoption of an assessment procedure with some prescribed elements while some may be adapted to the context at hand.

At Chalmers, for example, the degree project assessment consists of an oral component and two written components. The oral part consists of the project presentation and defence, opposition on one other project, and participation at two other project presentations. The written components are the planning report and the final report. When two students are performing the degree project together, the final report should include a contribution report. The final report is published as an open access e-report in the Chalmers publication library.

Mainly, it is the report that can be adapted to the specific project – a design task, a simulation, an experimental investigation etc. At the same time, the report should demonstrate the student's writing ability as such as well as demonstrate that certain other outcomes have been reached: depth of knowledge in the field of study, knowledge integration etc. Assessment in a formative sense, i.e., to give students feedback on their learning process, is

according to the interviewed faculty primarily given to support problem formulation and report writing. The interviewed faculty further argued that tasks were the most critical.

The interviewed faculty tended to consider the project outcome as the most important assessment criteria. It is the main goal: If this goal is met it shows that the student is mature to start work in industry. However, the same faculty admit that a degree project that has not met its project goals may pass, if the student(s) have done a systematic and thorough job. At the same time, when asked the question of which deficiencies in a report they most often require be changed prior to accepting a weak report, the majority points to linguistic and structural changes. The report is the dominant assessment instrument and is pushed to the foreground regardless of its planned weight in the assessment, perhaps even more so in an assessment that is argued to be holistic.

However, many faculty further argue that “demonstration of independence” is the most important role of the degree project. But there is no assessment criteria or format that evaluates “independence”. The correlation between project result and independence can be debatable in several ways: Is a good project result with much help from the examiner always worth a better grade than a not so good one with little help? How should varying time to reach the result be considered?

At Chalmers, there was until recently no stated assessment criteria for degree projects. Now there are criteria for fail, pass and very high quality related to the intended learning outcomes [19]. The criteria are not given a fixed weighting, the examiner is given the freedom to select certain criteria that suits the context of the specific project and to make a holistic assessment. These assessment criteria were however stated in a university-wide fashion, which several faculty found problematic. Their criticisms were clearly rooted in their background. “*The level required for very high quality is too high. It would signify doctoral level research*” (materials science professor) or “*The criteria are too research-oriented and do not fit product development projects*” (product development professor). The difficulty to state degree project assessment criteria applicable to several disciplines has been observed before [20], [21]. Nevertheless, in the current Swedish national system for evaluation of higher education [1], degree projects from across an entire field, e.g., “engineering” including mechanical, electrical, civil etc will be assessed against a common set of criteria. To prepare, Swedish universities need to state university-wide degree project intended learning outcomes and assessment criteria and evaluate the applicability of such and to what extent they need to be complemented by program-specific ones.

DISCUSSION

The basic aim of this paper was to discuss the applicability as well as the potential contribution of constructive alignment to higher quality on degree projects. Such a discussion would need an assumption or definition of what high quality degree projects are. However, the quality is intangible and difficult to define even though many of the interviewees stated that they could easily determine whether a thesis holds good quality. Based on interviews and the criteria for evaluation at Chalmers, we propose the following:

The quality is dependent on the problem, the process, the final result and the report:

- The problem should be open-ended both with regard to method and result. It should demand synthesis of previously gained knowledge together with deepened knowledge in a specific area. It should be supported by engaged clients and mirror the future professional activities.
- The student should show a *high degree of independence* and work in an organized manner, managing a time schedule and attain project goals including handle unforeseen conflict in demands. She or he should demonstrate ability to reflect and motivate selection of methods or solutions.

- The resulting solution should solve the stated problem, show novelty and be advanced from an engineering aspect. It should be scientifically based or show good engineering practice, e.g. handle several or conflicting demands.
- The report should be well written with pedagogic structure, correct language and as short and concise as possible but still contain everything necessary.

Let us now return to our research questions:

To what extent is CA applicable for degree projects?

Common intended learning outcomes as well as teaching and assessment activities can be identified for degree projects but are less crisp than for a course. To make use of CA to its full advantage, we probably would need to state intended learning outcomes (ILO:s) on the university, program and contextual level. Today learning outcomes are stated on the university level and in some cases also on a program level, but in both cases the ILO:s are general in nature and the perspective is more oriented towards a program manager rather than individual teacher.

Teaching practice differs significantly among faculty and departments. As mentioned, it is clear that the difference in teaching at different departments is coupled to different views on students' autonomy. Common for all is, however, that most time is spent on planning in the beginning and report feedback in the end. CA would be applicable and in fact also highlight the need for formative feedback to strengthen the process towards the ILO:s. It could also be a reason to exchange teaching best practice among faculty.

Assessment is today, as mentioned above, mostly focused on the written report. When CA is to be applied it most likely would introduce the need to assess also other elements in the process, which would be of benefit. The interviews showed that "developing independence" was an important objective which would be quite difficult, if to be assessed.

How can the "aha" experience of working with CA for your own course be experienced by Degree project examiners/teachers?

This is somewhat doubtful today as the teachers do not control the course goals, or the task or all of the teaching. Learning outcomes etc need to be contextualized for the particular project if this is to happen. More development is needed to advise teachers and students on how to create such contextualizations.

How can CA for thesis projects contribute to higher quality? Why/why not?

The quality as defined here consists of four parts; problem, process, result and report. We claim that the application of CA could have a positive effect on the quality in all four aspects as described below:

- A dialogue between teachers and between teacher and student to design the contextualized ILO:s could improve problem formulation quality. Such a discussion would support views on what constitutes good (or poor) quality. In addition CA would point to the need for integration of specific topics and clarify these goals for faculty who need to embrace them. It could also help to identify professional skills topics such as intellectual property rights that should be taught by specialist teachers.
- The process could become of higher quality. Since faculty would need to have a well-reasoned view on teaching components, CA could result in a more process oriented view on degree projects. The non-specified nature of the learning outcomes can be utilized to force students to take more responsibility and develop independence.
- The quality of the resultant solution could benefit from both improved and clearer objectives as well as a well-reasoned teaching approach. By extending the

assessment to the process, beyond the written report, the quality could be further improved.

- The quality of the report as defined here includes also writing skills as such, which today often is not assessed. The quality could thus benefit if the writing skills are clearly stated in ILO:s that are aligned with teaching and assessment.

In addition it needs to be stated that many of the elements that faculty says contribute to high quality are skills that are developed during the full education and CA in the degree project cannot replace a well planned and proactive curriculum.

CONCLUDING REMARKS

Degree projects fulfil a special role in Swedish higher education. Through the degree project, the students should demonstrate the theoretical knowledge and practical skills required for independent professional practice. DP:s can be described as project courses, but have some unique characteristics that make them challenging to teach: the larger task variation, the requirement on student independence etc.

In the paper, we have examined current DP practice and regulations for Swedish engineering degree projects from the viewpoint of the theory of constructive alignment.

We find that CA is applicable to DP:s at least three levels: the university-wide, the program-specific and the project-specific levels. They all play important roles: University-wide and program-specific ILO:s are essential for stating general intended learning outcomes for DP:s and for connecting DP:s to the whole of the education. They also have a function in accreditation/external evaluation: do the ILO:s of an institution meet governmental requirements? However, if the specific educational situation should be supported by CA, the elements of CA have to be worked out on the project level: contextualizing ILO:s, teaching and learning activities and assessment formats to the task at hand, while ensuring that also high-level goals are fulfilled.

At Chalmers, a university-wide framework for DP:s has recently been introduced. The framework includes a common set of ILO:s, guidelines for supervision, and assessment formats and criteria. In practice, however, DP teaching is a rather individual business. Nevertheless, some common views and approaches can be identified from the faculty interviewed, including the most important goals: (a) demonstrate independence in the engineering context, (b) solve the problem, (c) formulate the problem adequately, (d) write a well-structured and written report, (e) reflect on the results and the process. However, we observe that much of the feedback is given on the written report. This probably means that the linguistic and formal qualities of the report play a larger role in the assessment than indicated by the priority list.

Chalmers faculty, as well as the Swedish government, view "independence" as a key capability to be demonstrated through the DP. However, we have not been able to identify any clear ILO:s that define what "independence" is. There is no consensus on appropriate teaching and learning activities for developing independence. Some faculty argue that independence requires that teaching is kept to a minimum. The risk is that the same attitude seriously limits the developmental potential of the DP, however. Also, the main assessment instrument, the final report, is limited as a format for demonstrating independence.

Finally, we argue that application of the CA framework to DP:s can support work towards a positive development of DP quality. We have begun this journey but realize that there is much more work needed to develop the CA components for use in DP:s, and for the implementation across the campus. One of our prioritized tasks for the near future is methods and guidelines for contextualizing DP ILO:s. Another is to reconsider the

relationship between the whole of the education program and the DP. Do our programs prepare in the most purposeful way for the student's execution of the DP?

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FOUNDATIONS FOR A NEW TYPE OF DESIGN ENGINEERS – EXPERIENCES FROM DTU MEETING THE CDIO CONCEPT

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ABSTRACT

Since 2002 a new design-engineering education has been in operation at the Technical University of Denmark. It fulfils the requirements in the CDIO concept but builds in addition on a change in what is considered core disciplines in engineering. Three fields of knowledge are represented almost equally in the curriculum: natural and technical sciences, design synthesis and socio-technical analysis, which adds to the dominant focus in engineering on natural and technical sciences. Combined with the integration and coordination of disciplines, a series of projects providing a progression of challenges to the students learning, and a focus on the outcomes of the learning processes of competences needed in design engineering, the curriculum represents a radical innovation in engineering curriculum.

The paper describe the foundational elements of this educational program and present an assessment of the key factors that has made this program attract new groups of students to engineering including an almost equal recruitment of male and female students. In outcome and performance terms the educational program at the same time has delivered a quite efficient study environment for students. Since 2007 graduates have finished every year and an evaluation of the education based on the graduates and their employers' experiences supports the visions of the curriculum and adds to what is needed to reform engineering education.

The paper presents a critical comparison of the CDIO basic standards and principles with the learning content and experiences from the design-education at DTU and raise three questions to whether the advice provided by the CDIO syllabus satisfies the stated principles. The critique points to the following: (a) conceiving not being taken serious in the CDIO syllabus, (b) a too narrow view of engineering knowledge ignoring socio-technical insights, (c) the importance of engineering practices and competences in creating authentic assignments, (d) to reverse the hierarchy of topics and disciplines, and (e) a need for mechanisms to coordinate curriculum and cross-disciplinary cooperation. The creation of successful reforms in engineering education does not alone result from introducing project or problem based learning in the classroom. There is a need to focus on the objectives and disciplinary support for project assignments understanding the scattered character of technical disciplines. There is also a need for introducing measures that support teams building and continued cooperation among teachers to overcome the isolation.

KEYWORDS

Design-engineering, socio-technical competences, team work, authentic projects, disciplinary integration.

INTRODUCTION

Since the 1990s questions have been raised by industry and educational planners both in the US and Europe to the scientific orientation of engineering education as it has developed since World War II. The problems include a lack of practical skills in modern engineering training, a mismatch between the need of industry and the scientific knowledge taught, and the kind of analytical qualifications as objectified knowledge being awarded in engineering education compared with visions of engineers as creative designers and innovators of future technologies. With its emphasis on science and knowledge structured around technical disciplines, engineering education has developed into an education of highly technically skilled, specialized cooperative workers rather than innovative and creative engineers of technology for society. Following the continued development of technology has led to an increasing number of specialized fields and educational program characterized as 'expansive disintegration' by Williams [1] critical accounts have pointed to a need for reforming engineering education.

From this critical outset the knowledge and broad innovative orientation needed to produce creative design engineers able to cope with contemporary technological change have been as missing in engineering education. Several educational initiatives have addressed these issues in the last two or more decades outlining plans to reform engineering education. Some focus on engineering curriculum or the pedagogy and learning modes employed; some develop completely new engineering programs based on new technologies. These approaches seem to be confident in the achievements of engineers in society and argue for the continuation of a traditional science-based engineering curriculum [2,3]. Other initiatives combine business, management, and organizational understanding with engineering, or they alternatively emphasize the creative design aspects of engineering integrating aspects from other initiatives.

Common to most initiatives has been that they share the view that technology and the natural sciences are the two basic contributors of knowledge to engineering. They do not raise critical issues related to the social and institutional dependencies of technology. Engineering schools and professional institutions at large have supported the idea of a close relationship between science and technology by even asserting that natural sciences form the core foundation of engineering. Also contemporary developments in the natural sciences and engineering sciences have blurred the boundaries. New approaches of techno-science seem to be gaining ground as the characterization of the ties between modern science and technology, leaving neither one in a subsidiary role [4]. These new approaches do though recognize technology as a contributor to scientific achievements and thereby change the relationship between nature and technology. The question is whether these accounts are satisfactory in understanding and coping with the contemporary problems in engineering education in relation to the demands from engineering practices at large?

In this article the focus will be on the role of engineering design in contemporary society and the knowledge base and skills needed to perform engineering design. Based on a brief historic account of the controversies in engineering between practice and theory and concerning the core knowledge base the engineering education in design & innovation program will be introduced. The emphasis in the presentation and discussion will be on the combination of learning strategies and disciplinary knowledge components that constitute the curriculum and the program at large including its research foundation. From the outset engineering competences in design synthesis and socio-technical analysis building on the research field: Science and Technology Studies (STS) have been foundational for the reform of engineering

education implied. These additional components have also been agenda setting for the teaching of mathematics and technical subjects.

Several of the reform components found in the design & innovation program are also included in the requirements set up in the standards and syllabus of CDIO that is the acronym for a engineering reform initiative emphasizing that the four basic activities in engineering: Conceive, Design, Implement and Operate, should also be reflected in engineering education [5,6]. Of special importance for this paper is the advice given by CDIO on how to learn to conceive problems and carry out the design synthesis, which we will discuss and contrast to the approach taken in the DTU design engineering program. We seem to agree on the rather ambitious claim that engineers should be trained to 'build systems and product for the betterment of humanity' [A,p.4], but what does it take? Another topic of relevance is the structure of knowledge and the ideas of what is fundamental and in which order in the learning process should topics and disciplines be introduced. Despite this CDIO initiative's visions for reforming the engineering education with more focus on engineering practice, the fundamental in engineering education is still perceived as in-depth technological and scientific knowledge, since the baseline assumptions is that: 'The development of a deep working knowledge of technical fundamentals is and should be the primary objective of undergraduates engineering education' [5,p.5]. This implies a questionable hierarchy of knowledge as outlined in the syllabus [6,p.55-56] and a build up of design skills with the outset in technical knowledge [6,p.108]. In the last section of the paper these contrasts will be discussed.

ENGINEERING EDUCATION – A BRIEF HISTORY

In order to understand today's situation in engineering education and the emphasis on scientific knowledge, we must consider one of the most important historical changes in engineering education – the construction of a science base for engineering. This development resulted partly from the increase in public and military funding of engineering research during World War II, partly from attempts to develop a more theoretically based foundation for engineering. The program to establish a science base for engineering created an elite group of theory oriented universities and technical schools of higher education in both the United States and Europe. At the outset there was a gap in engineering curricula between science classes based on high degrees of mathematically formalized knowledge, and the more descriptive and less codified technical subjects. Controversies resulted in positioning technical sciences as secondary, or applied, in relation to the natural sciences. However, the new era of expanding technical sciences lessened these controversies because of its increased focus on innovation and awareness of the close interactions between specific areas of science and technology.

During the first half of the 20th century, polytechnic universities had to fight for acceptance. They were acknowledged for their foundations in science, but were questioned about whether they could conduct independent scientific research; or were limited to practical experiments with technical improvements and practical implementation. These controversies manifested themselves in the acceptance of doctoral studies at technical schools of higher education. In Sweden and Germany, as in many other countries, decisions about what should qualify as scientific achievement and who was qualified to judge were very controversial. The controversy ended with an acceptance of technical or engineering science as a distinct area of scientific inquiry, although the image of engineering science as merely applied natural science continued to dominate many discussions about the character and role of technical sciences. Sponsorship of fundamental studies in a variety of areas supported the trend away from practice-oriented research and education resulting in critique from industry [7].

The post-war decades saw the rise of systems engineering and thinking as broadly applicable engineering tools [8]. Systems sciences that include control theory, systems theory, systems engineering, operations research, systems dynamics, cybernetics and others led engineers to concentrate on building analytical models of small-scale and large-scale systems, often making use of the new tools provided by digital computers and simulations [9]. Whereas systems engineering of the 1950s could be narrowly analytical and hierarchically organized, new ideas of technological systems in the 1980s and 1990s focused on the relationship between technology and its social and industrial context. This new relationship and understanding of the natural and technical sciences is reflected in the notion that engineering as techno-science developed in the field of sociological studies of science and technology to reflect the new intimate relationship between these fields of science [10].

Changes in the foundation of engineering education, with the expansion of science-based technical disciplines, also has led to changes in the curriculum of traditional vocational schools of engineering, as well as funding for research. Though having different names, 'polytechnics' in the United Kingdom, 'fachhochschulen' in Germany, and 'teknika' in Denmark these schools shared common characteristics in recruiting students from groups of skilled technicians and supplementing their training with a theoretical education, while maintaining a focus on industrial practice. As a result, the schools inherited the experience-based, practical knowledge, and skills of students who had previously worked as apprentices in construction firms, machine shops, and industry. At the same time, the decline in the apprenticeship training of craftsmen and skilled workers began to undermine the recruitment lines of the polytechnics [11].

Conflicting 'ways out' – specialization and new modes of learning

The growth of the use of technology in the later half of the 20th century, in combination with the large investments made in engineering research by industry and by research institutes and universities, has resulted in tremendous growth in the body of technological knowledge, the number of new technological domains, and specialized technical science disciplines [12]. Differentiation in engineering specialties put pressure on engineering education to cope with the diversity and to keep up with the frontline of knowledge in the diverse fields. These developments have also resulted in a growing number of new specializations in engineering. Changes in the demands for specialization created tension between generalized engineering knowledge and the specialized knowledge needed in individual domains of technology and engineering practice. Examples of these specializations include highway engineering, ship building, sanitary engineering, mining engineering, power generation and distribution engineering, offshore engineering, aeronautics, microcircuit engineering, environmental engineering, bio-engineering, multimedia engineering, and wind turbine engineering. This development called 'expansive disintegration' [1] reflects the combined expansion of the number of technologies, specialties and disciplines on the one hand, and the continued disintegration of what once was the unity and identity of engineering on the other.

General pedagogical reform based on project-oriented work are also argued for giving students a broad understanding of engineering work and problem solving, with less emphasis on theoretical knowledge represented in the courses and disciplines [13] which is also found in e.g. the CDIO initiative [6]. In a less radical manner many engineering schools have tried to add certain new personal skills to their requirements and curriculum by complementing the natural and technical science teaching with training in communication skills, group work, and project management. These are competences that are implied in the project-oriented model and in the less demanding problem-based learning model.

The dominant role of technology demands multidisciplinary approaches, and challenges the science-based, rational models and problem-solving approaches. These demands have given rise to new areas of engineering education. For example, in the field of environmental studies, the need for new approaches in industry based on cleaner technologies and product chain management challenged the already established disciplines in sanitary engineering based on end-of-pipe technologies and chemical analysis. Another example can be found in the field of housing and building construction engineering. The need for integrating both social and aesthetic elements, as well as user interaction in both the project and use phases of construction, led to several attempts to overcome the traditional division between civil engineering and architecture.

The decade of the 1990s was not the first time that concerns about the role of technology in society had surfaced, but this time the questions raised issues of a more fundamental nature concerning the content of engineering education and the impact on technology exemplified with controversies about highway planning, chemicals in agriculture, nuclear power plants, and the social impacts of automation. The concerns questioned the role of knowledge about technology and some critics demanded a humanistic input into the curriculum with such subjects as ethics, history, philosophy, and disciplines from the social sciences [14]. This idea was based on the assumption that engineering students, through confrontation with alternate positions and opportunities to discuss social and ethical issues, would be better prepared to meet the challenges of technology. However, in many engineering education programs, these new subjects have ended up being add-on disciplines often not integrated with engineering and science subjects, contributing further to the disciplinary congestion in engineering. Changes in the role of technologies in a society where consumer uses, complex production, and infrastructures are increasingly more important, have led to more focus on the integration of usability and design features. The traditional jobs in processing and production have not vanished, but new jobs in consulting, design, and marketing have been created. These new jobs demand new personal and professional competencies, and require new disciplines that contribute to the knowledge base [15].

New approaches to design and disciplinary boundaries

During the 1990s, several engineering schools started new lines of education emphasizing engineering design skills and introduced aspects of social sciences into the curriculum of engineering design. These additions included technology studies, user ethnographies, and market analysis. The development of new and diverse technologies also reflects the limitations of technical sciences in being able to cover all aspects of engineering [16]. Examples of these reformed engineering programs can be found at e.g. Delft University in the Netherlands, Rensselaer Polytechnic Institute in the U.S., the Technical University of Denmark, the Norwegian University of Science and Technology, and several other places.

The description of an engineer's contemporary competencies might include the following: 'scientific base of engineering knowledge', 'problem-solving capabilities', and the 'adapt knowledge to new types of problems'. The focus is more often on problem solving, and less on problem identification and definition [17]. This is ideally taken up in the CDIO standard as conceiving, but not explicated were much in the latter detailed curriculum plans presented [6]. This focus emphasizes the problem of engineering identity in distinguishing between engineers as creators and designers versus analysts and scientists raising question about the foundation of synthesis knowledge and design skills. The underlying assumption in most training given by engineering schools on engineering problem solving is that engineers are working with well-

defined technical problems and methods from an existing number of engineering disciplines. This assumption does not answer the question as to whether engineers are competent in handling the social implication of complex technologies, and the even non-standardized social and technical processes where the problems are undefined and involve new ways of combining knowledge.

In this relation the limitations to engineering sciences and their models become a crucial part as does the understanding of technologies as hybrid constructs building on several both disciplinary and practice based knowledge components and embedding assumptions of use and social relations related to specific localities and historical settings even though these may become part of standardized socio-technical ensemble [18]. The other crucial aspect for engineering technology of the future is the handling of design challenges coming from the even more dominant role of technology in society and for the environment. This must lead to a redefinition of what the core competences of engineering comprise.

THE DESIGN & INNOVATION PROGRAM AT DTU

Since 2002, the Technical University of Denmark (DTU) has offered a new engineering education in design & innovation. This new bachelor and master program of 3 plus 2 years length represents a fundamental rethinking in engineering education. With an enrolment of 60 new students per year and twice as many qualified applicants, this new initiative is considered as a success by DTU. The new curriculum is targeted to meet the demands for competences from industry and society in the context of globalization and new cooperation structures in product development and innovation. The design & innovation education contributes to the renewal of the educational profile of DTU and is regarded as one of the recent major successful strategic developments.

An important motivation from the university management's side for providing the new education in design & innovation has been an interest in attracting more and new types of students having good grades from their high school graduation but not being attracted by the traditional engineering education curricula. The new educational profile has proven valuable for this purpose as it has recruited almost 50% of its students, from groups who explicitly would not have sought admittance to the engineering programs. The education has also been able to attract almost as many female as male students.

In the following sections the basic ideas and experiences from the development of the new engineering curriculum is described drawing on planning documents, curriculum plans and papers from many authors [19,20], however the main reference is an article by Boelskifte and Jørgensen [21]. Special emphasis will be given to the new type of knowledge and skills adopted with the socio-technical and synthesis dimension of the education. This is of significant importance and is accompanied by research activities in the fields of sociology of technology, innovation economics, organization and design synthesis from design thinking and engineering.

Socio-technical analysis and design synthesis

In preparing for the curriculum planning leading to the design & innovation education a revision of the disciplinary and skills content of what had become design engineering teaching within the mechanical engineering programs was put on the agenda at DTU. Taking the outset on one side in the competences needed by engineers to carry out design work in practice on one hand and bringing in the experiences from the two faculty groups initiating the new education at DTU new

topics and disciplines were taken up. The overall composition of the new program was illustrated with the flower model shown in figure 1 illustrating the three basic knowledge and skills components of which the program should build. The three components were seen as equally important for the training and learning process of the students.

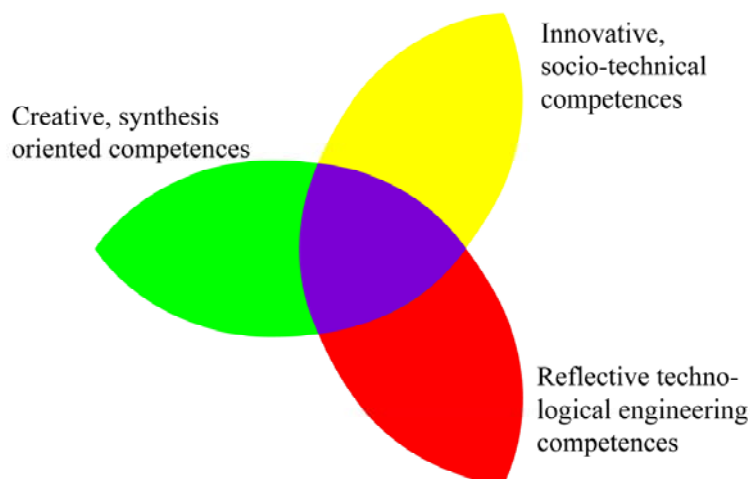


Figure 1. The multidisciplinary approach in the design & innovation education.

While the 'reflective technological engineering competences' are comparable to what might be seen as the core of traditional engineering education the idea of adding the demand for reflectivity was to point to the need for teaching this domain knowledge from the perspective of design. This entails a relative change in focus from optimizing within a given technical paradigm and concept to focus on the technologies features and qualities as a functional contribution to the totality of a design. This does not imply a rejection of problems of optimizing use and calculating specifics, but to provide a focus often lost in technical domain courses to be able to compare concepts and alternative technologies to reach a well functioning design.

Of the two other components also the 'creative, synthesis oriented competence' are included in many design oriented courses and projects in engineering education. Though the context in which the students operate often is provided from the position of an existing design concept or the application of an existing technology. This perspective of engineering design provides a conventional focus on the engineer's contribution mainly emphasizing the application of technological principles and the optimization of given concepts. Rather little attempt is given to the development of new concepts and to the involvement of users perception of what the functional demand as well as other aspects of use might imply. This has resulted in a dominantly introvert and technology determined type of design methods and models very useful to classic technology confined design tasks, but not providing e.g. the tools to analyze and include users in setting the design criteria and defining the design specifications. A variety of assessment tools have been developed to help engineers compare different conceptual solutions but most often constrained within the universe of functional specifications so common to engineering. The synthesis oriented competences of the DTU design program has therefore attempted to include user investigations and involvements as a basic mindset from the very first semester and also build the re-design activities of the second semester on studies of the use and problems related to existing products and technologies to provide the students with toolsets and approaches to tackle the demand side of products, services and systems.

The third component – the innovative socio-technical competences – is quite new to most engineering programs. Though it e.g. is taken up also in the design program at Rensselaer Polytechnics and is mentioned as an important challenge in the NFS-report 'ED2030: Strategic Plan for Engineering Design' [22], only few engineering curricula have included these topic as part of core basics of engineering. At some engineering universities socio-technical subject can be taken as electives and may be integrated in courses on the history of technology being part of the 'liberal arts' requirements for engineering education.

In the design engineering program at DTU a reverse strategy was chosen not viewing these topics as an add-on, but as core and basic competences needed as much as the mathematics skills by the students. This has resulted in a number of courses included in the program informing the students project assignments but given the status of being (social) science disciplines of their own right. The choice of theoretical foundation for teaching socio-technical subjects was based on almost two decades of experiences with teaching sociological and economic disciplines in the DTU engineering programs. During the 1990s these experiences were evaluated and a search for new and more interdisciplinary approaches was initiated. This led to an inclusion of the emerging disciplines – often still considered interdisciplinary – of the economics of innovation or broader 'innovation studies' and the sociology of technology inspired by constructivist views. The new disciplines were revolutionizing the field of science and technology studies (STS) by observing that social behavior and mechanisms are seamlessly weaving together social and material phenomena and objects.

Bringing in approaches from actor-network and other theories from the STS-field to analyze design-scripts, actors sense-making processes, assignment of qualities to technologies, arenas of development, co-design processes, material mediation and the staging of innovative activities these new topics have provided tools for design engineering students not only to understand and constructively analyze the context and use of designed artifacts, but also providing them with tools to understand the importance and limitation of the different spheres of knowledge provided in engineering.

Combined with the integration and coordination of disciplines, a series of projects providing a progression of challenges to the students learning, and a focus on the outcomes of the learning processes of competences needed in design engineering, the curriculum represents a radical innovation in engineering curriculum. Thus, the design & innovation education aims to give competencies to work within a spectrum of considerations and values from a diversity of professional specializations as well as user groups from everyday life settings.

Thematic semesters

Design can be defined as applying technologies in a social context. Neither subjects taught in basic sciences nor the technological subjects prioritize synthesis in content or means. Yet technology must be adapted to fit assignments or be part of innovation processes. This utilization of technology must be experienced if the student is to develop design competence.

The education opens up in the first semester by exposing the new students to the complex world of users and technology with the theme 'Meet the world of technology'. The semester includes courses in mechanics and materials, product design, and user analysis and visual communication. The semester also motivates and creates identity, introducing the mode of studying connected to synthesis, reflection and awareness. The project subject is 'User Oriented

Design' where contributions from all the different courses are integrated by the students in their analysis and problem solving.

The second semester theme is 'The good product'. Focus is on understanding the complexity of manufacturing i.e. from the first ideas to the production, introduction and use of a physical product. This sequence is studied from various approaches: functionality, properties, construction, production, methods and the socio-technical context (users, use, producer, sales, competition, culture etc.). In this semester, the project assignment 'Product Analyses and Redesign' is carried out in collaboration with companies donating products for analysis including the context of use. A redesign is carried out based on potentials identified in the analysis phase and here the students learn, that redesign also means redesigning the complete network of players involved in the product.

The third semester theme is 'Engineering construction'. This semester the students learn to carry out a complex design based on given specifications. The focus is on mutually coupled design assignments within the domains of mechanics, electronics and software. This includes selecting components and using them according to functional demands within the three domains and ensuring their mutual interaction. The project assignment 'Mechatronics design' includes a detailed conceptual design based on given specifications i.e. a product with a mechanical-, electronic and software content that further-more builds on knowledge, skills and methods learned in the integrated subjects like electronics and objects.

The fourth semester theme is 'Workspace design'. The core of the semester is a project with a company or an organization. The students themselves plan and execute an analysis of a given workspace and related work processes. Reflections on choice of methods and tools in the design process constitute a significant part of the project.

The fifth semester theme is Innovation and sustainability. The semester focuses on environmental- and resource issues connected to the development, production and disposal of products and systems. Importance is placed on methods to describe, assess and improve environmental and resource issues in a life cycle and a product chain perspective. Social and socio-economic aspects of sustainability are covered as well. The project assignment 'Product service systems' includes identification, analysis and assessment of a product and its system's environmental aspects and resource consumption, including reflections on the planning of design processes.

The last semester in the bachelor program include the 'Bachelor project'. This semester is the conclusion of the bachelor part of design & innovation. This project is supported by a course in scenarios and concepts which furthermore ask the students to reflect and report on the conclusions of former project assignments.

Projects and coordination

Project oriented work is the continuum of the design & innovation education. A chain of projects with a progression of challenges in various dimensions constitutes the spine of the syllabus. The basic idea is to combine 'learning by doing' with a structured learning sequence emphasizing elements of practice necessary to obtain specific competences in the three key areas.

Understanding and mastering working with design synthesis requires elements of apprenticeship relations to the professional. The student must experience the professional in action to

experience value based assessments and utilize this dialogue in connection with one's own creations. The learning process is thus primarily based on interaction and experience.

All through the thematic semesters, the multidisciplinary approach are taught through project assignments and by giving the students extensive training in the innovative process. Core to the semesters integrating project assignment is the coordination of courses and topics among the team of design teachers. The coordination may be one of the crucial elements contributing to make the course work and project function as a coherent and appealing program for the students.

Study lines at the masters level

The bachelors program of 3 years is providing one main line of progress and content for almost $\frac{3}{4}$ of the activities leaving the rest for students own interests to pick courses from the modular course program of a large number of technical disciplines as a complement to the design education. In contrast the masters program of 2 years is offering a larger variety of possible study lines each of which offers a certain orientation of the core design activities still providing a further progression in the students learning. The core elements comprise of a set of courses improving the knowledge and skills of the students in the fields of product design, user interfacing, industrial design, materials knowledge and an advanced project assignment demanding rather finished concepts or results from the products, services or systems that the students focus their design competences on. In parallel the students follow technical domain courses in a few field to reach a deeper understanding of the technologies and methods from these fields. Through this combination the candidates have a combination of a technical engineering specialization and their deep understanding of the field from having worked with design activities reaching the implementation stage.

In the framework of design & innovation four study lines are offered. They all share the common base of the master's but each offers the opportunity for a different focus:

- Prototypes and production
- Eco-design and sustainable transitions
- User involvement and co-design
- Workspace and systems design
- Design and innovation management

Each study line can be combined with a 'global semester' that has focus on 'people-centered' design building intercultural competences and related to local developing issues in either newly industrialized or developing countries.

Combining education and research

The starting point for the development of a new engineering curriculum in design & innovation was based on the work of a group of ten devoted and experienced teachers of engineering design and social science subjects based in the departments of 'Mechanical Engineering' and 'Manufacturing Engineering and Management'. It took more than one year to construct this new curriculum. Though the education was constructed at an already existing and old engineering university, the basic idea was to re-design the complete curriculum including the core engineering and natural science curriculum to create a coherent new education. The students seem to have embraced the new curriculum and the number of students' abandoning the education is very low.

The research program in design & innovation subsequently was developed by basically the same cross disciplinary team but also involving a network of Danish university-based research environments. Through research workshops where people from industry and university researchers and teachers meet and exchange experiences from practice and theory concerning innovation in product development a range of new research problems have been defined.

HAS THE PROGRAM DELIVERED A NEW TYPE OF ENGINEERS?

After successful operation of the design & innovation educational program since 2002, and having the first students graduating, the team behind the education found a need for having an evaluation being carried out of the program aiming at exploring whether the students through the 5 years ended up with a profile as heterogeneous engineers, e.g. having obtained competences within the fields of 1) reflective technological engineering competences, 2) creative, synthesis oriented competences and 3) innovative, socio-technical competences.

The evaluation was designed comprising of three phases: 1) workshops with graduates, teachers and censors, 2) a telephone survey of graduates and representatives of the graduates' employers and 3) qualitative interviews with censors, teachers, graduates and students. The outcome of the evaluation is reported in [23,24,25]. In this section the outcome of the evaluation and thus the challenging of reforming engineering educations are discussed.

Challenges identified through the evaluation

In the first phase of the evaluation three workshops were facilitated by the evaluators with graduates, teachers and censors affiliated to the design & innovation program. Based on these workshops, it was clear that the education meets its objective of providing the candidates with heterogeneous design competencies as specified within the three fields illustrated in the presentation of the program. Concerning study efficiency and flow the education also demonstrates the importance of providing a coordinated curriculum that motivates the students to follow plans and timelines. With respect to drop out rates and extended study time the education is among the best performers at DTU. But this is still a side effect of the planned curriculum as the principles were foremost introduced to reach the levels of integrated competences in design engineering.

However, the education also faces some challenges in relation to the priorities made in the curriculum construction. Since the education is designed with thematic semesters it provides less room for optional courses than more open, modular programs at DTU where the courses may be placed more freely. Applying a multidisciplinary approach in the education, e.g. teaching the students to shift between using technical, creative and socio-technical competences also raises a challenge in accordance to the graduates own self-understanding (identity) as engineers. The workshops as well as the telephone survey and qualitative interviews revealed that the students and the graduates experienced difficulties in defining their competences precisely when meeting their first potential employers. This was a result of breaking out of the established patterns of engineering disciplines and programs. When having experienced their first jobs and assignments this problem of identity seem to vanish in the comparison with other engineers and professionals in comparing their practical ability to carry out project tasks.

Related to this, it turned out to be a challenge for the graduates to ensure that they would fit into existing job profiles and practices. Phrased as the need for a conventional 'hook' into technical disciplines and production planning this was another problem relating to the importance of

convincing employers of the new type of design engineers. This was in particular mentioned by the sensors and the representative from the industry, however, it reflects a complexity, since emphasizing a need for a technical 'hook' might be a left-over from the traditional way of thinking engineering, where engineers had a more conventional science based profile. In practical terms this problem has not shown to be of detrimental importance since the design engineering graduates have had lower initial unemployment rates than graduates from other programs. As a consequence the curriculum has been changed improving the student's skills in bringing their design from a conceptual state into production preparation.

The other aspect of the need for technological competences is related to the way most engineering disciplines are taught. Most courses in technical sciences are focusing on theoretical models and optimization while their use as object of design in more complex constructions is given low priority. This often makes it difficult to combine different technical disciplines even though this would be ideal for a design engineer.

Employment patterns and motivations

To gain an understanding of the graduates' careers, e.g. patterns, workplaces and applied competences, the second phase of the evaluation was a telephone survey of all graduates and selected representatives of employers. Out of a total of 78 graduates, 72 were interviewed, equal to a respond rate of 92%. In addition 14 representatives of employers were interviewed, aiming at exploring the graduates' competences. The representatives of employers were among other issues asked what had motivated their decision of employing a design & innovation engineer. To this question they responded that they were on the look-out for engineers with a specific profile and competences meeting the following requirements.

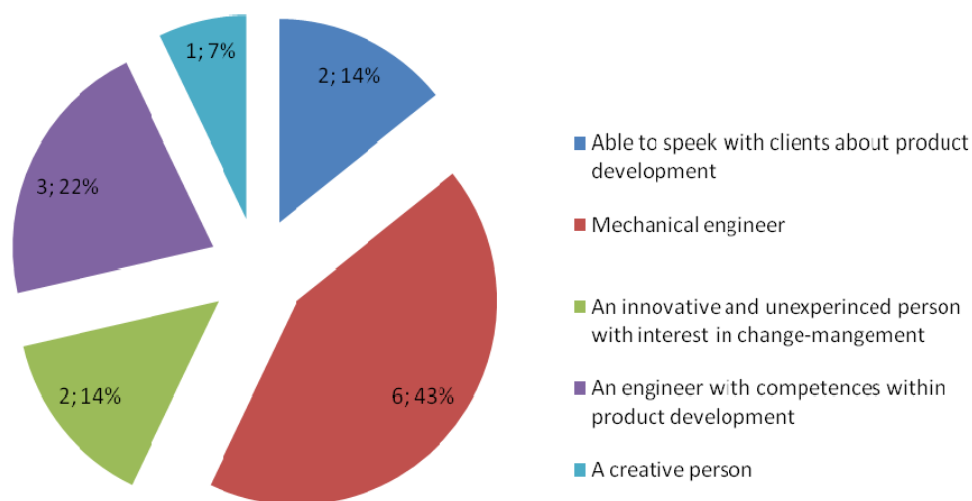


Figure 2. The representatives from industry's motivation for employing D&I engineers.

Important insight into the characteristic of the design & innovation engineers was drawn by the representatives of employers. They emphasized that the graduates have strong competences in relation to generating concepts, working and approaching problem-solving in an open and creative way and yet in a very structured way. They are very user-oriented, while still maintaining

focus on the product or the technological system to be developed, as well as the graduates upholds a strong culture for teamwork.

In general the evaluation concludes that the graduated design & innovation engineers succeed in upholding competences making them heterogeneous engineers, which also is illustrated in the different job functions they obtain. All the interviewed graduated design & innovation engineers reflect on their education as having been interesting, challenging, and relevant for their present job function. Further, the representatives of the employers seem satisfied with the education, even though they in some cases requested needs for specific competences, such as more insights into plastic materials etc. Interestingly while the employers' requests more technical competences, the graduated engineers as well as the students mentioned that the priority of weighing creative and socio-technical competences in line with technical competences is what makes the education interesting and unique compared to the more traditional engineering educations.

CDIO AND THE DESIGN & INNOVATION PROGRAM

Even though the design & innovation education at DTU in many respects seem to be modelled by using the CDIO principles as the outset there are some crucial differences in some very important dimensions. Besides the historic fact that the education at DTU was developed independently from CDIO the differences open for some important dilemmas concerning the future of engineering education.

One important conclusion from the evaluation of the design & innovation education is, that the priority of weighting creative and socio-technical competences in line with technical competences is what makes the education interesting and unique for industry and other employers compared to the more traditional engineering educations. When comparing the disciplinary composition with the visions and ideas of CDIO a very fundamental difference shows since the technical competences are given the main priority combined with an add-on of communicative and interpersonal skills. In the listed priorities of the CDIO syllabus 'technical knowledge and reasoning' is given the first priority followed by 'personal and professional skills and attributes' and 'interpersonal skills: teamwork and communication' which is a rather conventional way of providing an important add-on of skills and attitudes to the very basic technical knowledge. First as the fourth priority 'Conceiving, Designing, Implementing and Operating systems' in the enterprise and social context' show in a rather general way without specifying what knowledge might be needed to reach these competences [26,p.55-56].

The priorities of this list are seen as fundamental as stated in the following:

The CDIO Syllabus is a list of knowledge, skills, and attitudes rationalized against the norms of contemporary engineering practice, comprehensive of all known skills lists, and reviewed by experts in many fields. The principal value of the Syllabus is that it can be applied across a variety of programs and can serve as a model for all programs to derive specific learning outcomes. [26,p.49].

When going a little more into details with the content of the four acronym letters the following defining table is found:

Conceive	Defining customers needs, considering technology, enterprise strategy and regulations, and developing
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	conceptual, technical and business plans.
<i>Design</i>	Focusing on creating the design; the plans, drawings, and algorithms that describe what product, process or system to be implemented
<i>Implementation</i>	Refers to the transformation of the design into the product, including hardware manufacturing, software coding, testing and validation.
<i>Operate</i>	Uses the implemented product, process or system to deliver the intended value, including maintaining, evolving, recycling, and retiring the system

Figure 3. The Four elements of the CDIO concept [6,p.8].

The dilemma related to these elements is that they seem to neglect the socio-technical competences as well as competences to work with synthesis as also demonstrated in the following definition of the CDIO goals:

Master a deeper working knowledge of technical fundamentals defined by: Engineering education should always emphasize the technical fundamentals ...deep working knowledge and conceptual understanding is emphasized to strengthen the learning of technical fundamentals ...In a CDIO program, the goal is to engage students in constructing their own knowledge, confronting their own misconceptions". . Instead the CDIO concept with its three overall goals seems to be enrolled in a classical techno-science discourse, emphasizing the 'technical fundamentals'. [6,p.20]

While in the DTU program the phase of conceiving the problems and demands that can be identified in the use context of designs of products, services or systems has been given a very high priority in accordance with the earlier stated imbalance in engineering education between (socio-technical) problem identification and (technology-driven) problem solving [17] not much can be found elaborating of the meaning of 'Conceiving' in CDIO. In fact this 'letter' has only been given a few lines in the complete book outlining the principles, goals and standards. In the listed priorities of the syllabus point 4.3 detailing what is meant by *conceiving* includes: 'setting systems goals and requirements; defining function, concept and architecture; modeling of systems and ensuring goals can be met; project management' [26,p.56]. At another place *conceive* is understood as 'interaction and understanding the needs of others' [6,p.28]. Nicely followed up by this general statement:

In a CDIO program, experiences in conceiving, designing, implementing and operating are woven into the curriculum, particularly in the introductory and concluding project courses. [6,p.28]

This underpins that the focus in CDIO still is on engineering as a self-contained and complete discipline of both knowledge and skills implying that no other types of knowledge is given a similar status.

Another difference in approach relates to the content of semesters and the hierarchy of the topics included in the education and how they are placed in the progression of semesters. The basic structure of CDIO is illustrated in the following figure.

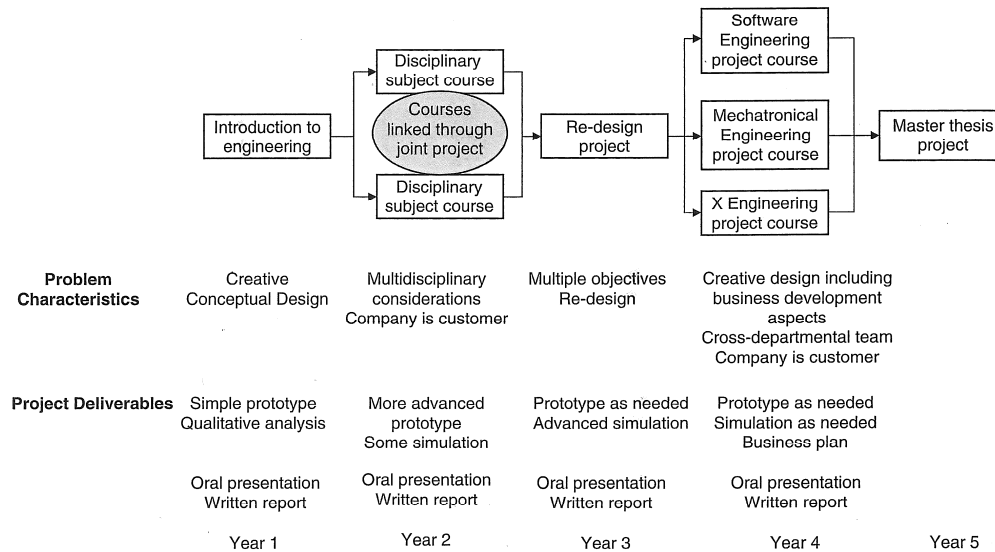


Figure 5. Semester plan – integration of design-implement in the curriculum [27,p.108].

Though the semester plan shows that design problems are part of the learning outcome it does not state this as something needing support from theoretical knowledge or skills as the topics included are mainly courses in technical subjects as outlined in the following:

Introductory first-year courses usually include basic design-implement experiences. These early experiences have significant positive effects on first-year students. Students are introduced to structured engineering problem-solving with opportunities to apply fundamental engineering principles. In addition, they learn to work in teams and communicate their progress and results. [27,p.106]

While the program at DTU has seen it as important to create a mindset of including user perspectives at the very first semester not missing the technical and natural science competences the practical vision of CDIO still has a strong emphasis on technical knowledge:

Early introduction to disciplinary knowledge is effective in building students' enthusiasm for engineering. [27,p.106]

The technical focus is followed also in the outlines of the following years emphasizing design as the production of technical artifacts leaving the needed knowledge implicit and to the readers own ideas:

... advanced design-implement experiences are usually planned for 3rd- or 4th-year students ... Advanced design-implement experiences are technically challenging in all phases of the project. The work includes design and implementation of student-developed components, as well integration, testing, verification and validation in conjunction with commercially available components or those developed by other students". [27,p.106]

When it comes to the organizational skills of operating also very few details are given. This leaves the CDIO conceptual framework in a dilemma of having introduced very much needed

new pedagogical methods and team work assignments into engineering education but not providing a deep discussion on the type of knowledge, identity and skills needed to meet future demands.

APPLYING A MULTIDISCIPLINARY APPROACH IN ENGINEERING EDUCATIONS

The role of engineers in technology and innovation is often taken for granted. Even in future-oriented reports on engineering, there is a tendency to expect problem-solving abilities in societal and environmental issues from engineering, without challenging contemporary foundations of engineering curricula. Innovations during the last decade are leading to changes that may make the role of engineering less central in the future. Policy and management attempts to govern innovation processes have also broadened the scope and shifted the focus from technological development and breakthroughs to a broader focus on market demands, strategic issues, and the use of technologies. [28,p.233]

Lessons from designing the design & innovation education program, point towards a need for new mechanisms of coordination in the curriculum as well as a need for cross-disciplinary cooperation. The creation of successful reforms in engineering education does not result from introducing new projects or problem-based learning processes in the classroom alone. There is a need to understand the isolated and often scattered character of individual disciplines and introduce measures that support the teams building and continued cooperation among teachers to overcome the isolation of individual courses and disciplinary approaches.

Even though the design & innovation education at DTU is a success both of the perspectives of the involved actors as well as seen from the perspectives of DTU, applying a multidisciplinary approach to engineering educations is a challenge, since the education continuously needs to consider and reverse the teaching and curricula ensuring the education keeps positioning itself in the forefront of innovation. Some of the challenges the evaluation of the design & innovation education points towards are 1) how to keep ensuring a progression in the students competences, 2) are the education to put more emphasis on opportunities for specialization, 3) how to ensure opportunities for in-depth studies while maintaining a wish of educating heterogenic engineers.

Applying a multidisciplinary approach in engineering education requires that the role of knowledge in learning and the creation of engineering identity implies a need to overcome the taken-for-granted approaches in curriculum development emphasising the role core science-based disciplines instead of the domain competences needed from field of practice [28,p.235]. In this respect does CDIO not meet the challenges from the domain of engineering design – there is still much room for improvement and some ideas and experiences can be found in the design & innovation program at DTU.

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MAY AN INCREASED FOCUS ON STUDENTS' PERSONAL DEVELOPMENT CONTRIBUTE TO INCREASED MOTIVATION, BETTER ACADEMIC PERFORMANCE AND TEAMWORK IN ENGINEERING PROGRAMS?

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ABSTRACT

Our hypothesis is that an increased focus on engineering students' personal development in the curricula will increase their motivation, academic performance and teamwork. With this starting point we have developed the EDIT model for personal development aimed at the engineering students in the 5-year EE, CE and SE programs at Chalmers University of Technology. The EDIT model comprises the topics and the process and timing of the delivery in the curricula at the bachelor level. It is based on behavior-scientific theories and on 40 years of experience in guiding engineering students at Chalmers. The fundamental concept for the model is that introspective knowledge gives extrovert ability. It comprises four topics: Motivation and learning, Teamwork, Leadership, Career and professional life, and a complementary reflection package. Based on motivational theory and pedagogical literature, we discuss why we have selected these topics and how they should be implemented in the curricula and syllabi to facilitate the development of the students. We argue that these topics should be placed in a context and at a time that makes them meaningful to the students. We give practical examples from the project test implementation and discuss practical issues that are likely to hinder the long-term success. In conclusion, we find that there is some evidence from our experiments that motivation and teamwork is improved. The possible effect on academic performance is so far very hard to assess.

KEYWORDS

Personal development, reflection, motivation, learning, teamwork, leadership, career planning, pass rates, generic skills

1. INTRODUCTION

In this paper we present initial results from a multi-year project that aims at increasing students' motivation, academic performance and teamwork through an increased focus on personal development in the Electrical, Computer and Software Engineering programs at Chalmers University of Technology (Chalmers for short) in Gothenburg Sweden. In this section we set the scene and explain why we undertook this project.

In Sweden and at Chalmers there are 3-year engineering programs and 5-year engineering and architecture programs. Since 2005, the 5-year engineering programs at Chalmers are organized as 3-year bachelor programs followed by 2-year master's programs, according to the Bologna model. The bachelor program in the 5-year engineering program is kept

separate from the 3-year engineering program, thus there are now two types of 3-year programs running in parallel. In this paper we are concerned with the 5-year programs in Electrical Engineering (E), Computer Engineering (D) and Software Engineering (IT) programs. These we call the EDIT programs for short.

Since around 2005, the 5-year EDIT, and also the 3-year ED programs, have suffered from a serious decline in the number of applicants which has resulted in a significant decrease in student volume in the programs, but also in less motivated students and a rather poor recruitment of female students and students from a non-academic background. This deficiency has in turn resulted in lower academic performance, measured as pass rates at course level as well as at the program level.

Due to the poor recruitment and decrease in academic performance a curriculum-reform study was initiated in 2008 by the Chalmers vice-president of education and continued in 2009 when the main task was to propose a totally new program structure and curricula where students would be admitted to **one** 3-year program (well actually two: one for E and one for DIT) which would result in both a 3-year engineering degree and, if succeeded by a 2-year master's program, a 5-year engineering degree [1-2]. One belief was that such a structure would increase recruitment because it would be easier to understand for prospective students as there would not be a 3-year and 5-year program with the same name to choose between. On the other hand, students in such a program would have to make important choices within the programs already in their second year. One important outcome of this study is the fundamental idea of placing the engineering student and her personal and professional development at the center of the program and considering the teaching and learning activities (courses, projects etc) as means to achieve this development. That is, with this student-centered perspective the personal and professional development is the backbone of the curriculum. Here, the ideas of constructive alignment [3] and CDIO [4] played a central role. Constructive alignment (CA) was conceived as a method to use at the course level (Biggs). Biggs argues that students construct meaning from what they learn and that the teacher is to design a course such that its intended learning outcomes (ILOs), student learning experiences, and assessment is aligned [3]. Related is also "backwards design" [5]. However, CA has later also been used at the program level [6] to align student learning experiences, learning sequences over an entire program to program learning outcomes. The alignment has several purposes: one is to make sure that the constructed meaning is the one the teacher intended, a second one is to make the student take responsibility for his / her own learning, a third is to make the student expect success upon completion. In this context of professional engineering programs, personal development is a program learning outcome in its own right, as well as a means to an end.

The idea of having only one common 3-year program per subject area was not realized, mainly due to faculty opposition. But the idea of placing the personal and professional development at the center of the curricula prevailed in the management of the 5-year EDIT programs. Thus, a more modest and long-term curriculum-reform project was initiated and run jointly by these three programs in 2010. In this paper we describe the results so far of this project.

Our hypothesis is that an increased focus on the students' personal development will contribute to increased motivation, better academic performance and teamwork in our engineering programs. We approach these issues from a behavioral-science perspective rather than from a pedagogical perspective. In this project we have consistently used a student-centered and experience-based perspective and we have taken advantage of the 40 years of experience that three of us have as student counselors. The research and development reported in this paper, has been conducted through literature reviews, participation in conferences, discussions with leadership consultants and interviews with

employers, students and teachers. During the project, different elements were tried out and evaluated in the current EDIT programs.

This rest of this paper is organized as follows: In section 2 we give a short background on personal development and motivation theories related to our work. In section 3 we present the EDIT model of personal development and in section 4 we place this model in a context. In the following section we present the experiences made from the implementations in 2010 and we conclude by a return to a discussion and conclusion related to the answer to the question posed in the title.

2. PERSONAL DEVELOPMENT AND MOTIVATION

Personal development and motivation are related due to both being about acting on explicit or implicit goals.

2.1 Personal development

According to Aubrey, personal development can be defined as “activities that improve self-knowledge and identity, develop talents and potential, build human capital and employability, enhance quality of life and contribute to the realization of dreams and aspirations” [7]. Personal development can also be viewed as being closely related to coaching, where coaching aims at unlocking a person's potential to maximize his performance. It facilitates his learning rather than teaches him [8]. Most coaching writers argue that the purpose of coaching is personal development, but one also finds the term personal development in related disciplines such as cognitive therapy, client-centered therapy and the Socratic dialectic [9]. Over time, many different theories about and approaches to personal development have been brought forward. The result of an internet search suggests that personal development is a term for all that a person may develop individually, i.e. everything that gives an individual more control over her life and her feelings, makes her feel better and build stronger relationships with people in her surroundings. The term personal development can refer to becoming more productive and efficient in work and to simultaneously manage to stay focused on what really counts in life. Personal development is considered important and necessary for good health. However, exactly what personal development means, each person has to decide for herself. It is the goals of the individual that determine what personal development is and it is also the individual who is the driving force in the development.

Lennér Axelson and Thylefors argue that in your own internal dialogue an extensive self-knowledge emerges [10]. Also in the interpersonal dialogue, e.g. in the open and intimate conversation between people who know each other well, a comprehensive self-knowledge takes place. In this way you learn how you are perceived by others, both your strengths and your weaknesses, and you can use this feedback to change yourself if you want to. Knowledge in itself is a great asset since it inspires confidence and pre-understanding of who you are [10].

The socio-cultural perspective in pedagogy also emphasizes human communication as a means of learning and development. Säljö describes the social-cultural perspective and argues that humans develop through interaction with others and through sharing experiences with others [11]. By communicating what happens, the individual is involved in how its environment perceives and explains phenomena. Communication precedes internal meaning-making. Thus, one learns in the context of a particular culture and a particular societal community. The socio-cultural perspective identifies a channel (a form of human communication) through which learning and development takes place. “Communication is the link between the internal (thinking) and external (interaction)” [11].

2.2 Motivation

There are many motivation theories but they give no clear answer to the question "What creates action?" Early motivation psychology assumed that humans acted mostly driven by innate biological needs or by seeking rewards and avoiding punishment. Later, the ideas of a third driving force, a kind of internal motivation that creates satisfaction in managing and performing a task, have been established. Deci and Ryan developed what they call the self-determination theory (SDT). This theory claims that we have three innate psychological needs: competence, autonomy and relatedness. When these needs are met, we are motivated, productive and happy. Of the three needs the autonomy is the most important one [12]. Since the theory was first published, in 1985, almost a thousand research reports have reached to the same conclusion: Humans have an innate, internal driving force to be self-governing and to feel belonging to others. When that driving force is released you achieve more and live a richer life [13]. Pink draws the conclusion that genuine motivation is created through self-control, mastery and meaning [13]. Our interpretation of it is that humans, in order to do advanced things, need to decide how, in what way, when and with whom the task should be done. You have to be allowed to work on your own terms and feel partnership. Humans have an innate desire to develop and succeed in what they do. You want to perform better, experience engagement and be absorbed by the interest for the task, although the reward is absent. Internal motivation also arises when you feel that what you do is meaningful and when it is clear that the task will result in what you want and that you understand what use you will have of it.

Human needs are basically the same for all humans. However, depending on needs that have already been met, individual history and circumstances (i.e. childhood conditions, social and community context, values, etc.) the individual will be motivated by different things. Some are motivated by external factors: I have to pass the exam, otherwise I get no further financial aid; I want to get a job; I want a profession that guarantees a certain status; I want a high income; I want a certain affinity in the community. Others are motivated by internal factors such as the desire to develop and learn more, a genuine interest in certain things, etc. In personal development we want to support students in exploring their motivation. To manage a long and at times very hard education, we need to encourage the students to find their inner motivation, i.e. what makes them feel that studies and knowledge are joyful, that they have chosen both the topic of studies and to do the studies of their own volition and that the studies are meaningful for them.

What we want is to create an environment that facilitates the creation of this internal motivation rather than, as it often is today, that students are driven merely by external motivation factors. This we believe, we can achieve by designing the process, by emphasizing communication and relation and by working with the students' own goals. That is, by a focus on personal development.

3. THE EDIT MODEL OF PERSONAL DEVELOPMENT

We define personal development as having two dimensions: the inner dimension that is about self-knowledge and the outer dimension that is about social ability, figure 1.

An engineer with good self-knowledge has a higher ability to direct herself, adapt her behaviour, make well-considered decisions and in addition possesses a higher degree of well-being. An engineer with good social skills is able to socialize in both private and professional contexts and is able to cooperate with both superiors and subordinates even though the personal chemistry is not very well matched.

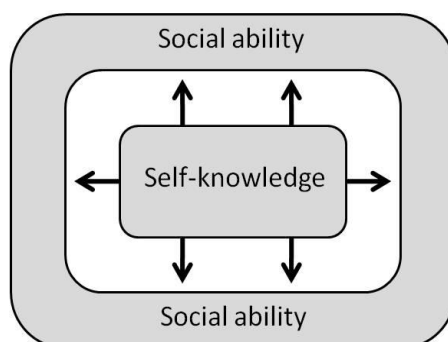


Figure 1. Personal development defined as having two dimensions: the self-knowledge in the inner dimension that leads to the social ability in the outer dimension.

3.1 Model contents

The first starting point when developing the model was the idea that an increased self-insight would lead to increased motivation, increased sense of responsibility, improved cooperation ability and an increased ability in making their own decisions.

Based on the ideas formulated by Lenn er Axelson and Thylefors, Luft and Ingham, Schutz, [8, 12, 13] and our own experiences from meeting students in counseling situations, we deduce that the more you know and learn about yourself the more competent you become, i.e., introspective knowledge gives extrovert ability. Thus, personal development consists of two dimensions; the inner one that deals with self-knowledge and the outer one that deals with social ability. A person having good self-knowledge has a higher ability to guide herself, is able to adapt her behavior in different situations, is able to make rational choices, is able to make well-thought-out decisions and, in addition, has a higher degree of well-being. A person having a high social ability is able to socialize in different contexts privately as well as professionally and is able to cooperate with all, subordinates as well as superiors, even if the personal chemistry is not matching. That person also understands her own and others reactions and behaviors better and is able to act based on this knowledge.

A second starting point is that it is important for human beings to feel a sense of belonging, to feel competence, to feel liked and that self-perception and self-respect is of vital importance for personal and professional efficiency [15]. This implies that it is important for our students to feel that they fit in, to feel that they have made the right choice, to feel that they can handle their studies and the study pace and that they feel a sense of community. It is therefore important that these aspects are addressed in order to facilitate increased pass rates. These statements are supported by the annual survey on youth attitudes conducted by *Ungdomsbarometern* [16] which shows that young people are concerned that the studies will affect the personal economy negatively, that they will make the wrong choice of education, that they have low motivation, that the study pace is high and that they will not pass the exams.

After literature studies and work on formalizing the informal knowledge from our extensive experience, we settled on a relatively narrow approach to personal development and many possible topics were left out. When discussing personal development with teachers, students and industry representatives we have found that they also mention and request "professional development". This term we take to mean professional skills. These are also important, but mainly excluded in our model, since we focus on topics that we believe are related to our end goals of better motivation and academic performance.

We propose a model for personal development in the curriculum enabling the students to acquire knowledge, methods, tools and abilities within four areas: motivation and learning; teamwork; leadership and career and professional life, figure 2. In addition to these four topics, a reflection package is added which helps the student identify and reflect on her development aiming at achieving increased self-insight. In our opinion, no self-knowledge will be gained without reflection so this is a crucial element in personal development.

In the **Motivation and learning** section it is important to get students to feel both motivated by affiliation and expertise. According to the Qualifications ordinance a graduating engineer should "demonstrate the ability to identify the need for further knowledge and undertake ongoing development of his or her skills". This goal is about developing effective methods for learning but also about reflecting on the limits of one's ability and to understand when upgrading of the competence is required.

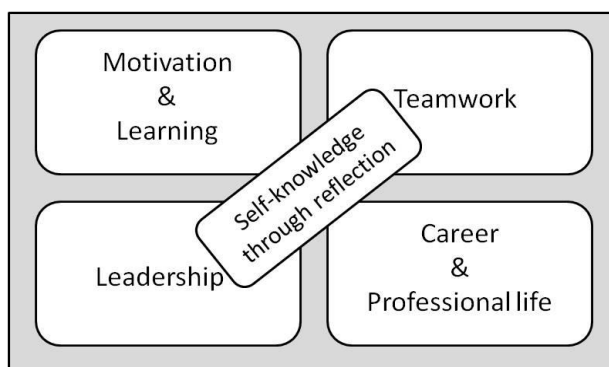


Figure 2. The EDIT personal-development model based on four topics and a complementary reflection package.

By offering early contacts with professional engineers and by working with and clarifying the student's own objectives underlying her choice of education, and by making a plan for achieving these goals, we will create accountability, drive and motivation and a sense of having made the right choice and a desire to stay the course. By adding study support activities such as Supplemental Instruction (SI) [17], student coaches and study skills sessions with a focus on training and reflection, we can support the students in feeling an increase in competence and in decreasing their fear that they will not cope with their studies.

In the **Teamwork** section the underlying ideas are that everyone should experience belonging, competence, and camaraderie. The Qualifications ordinance states that an engineer on completion of degree "should demonstrate the capacity for teamwork and collaboration with various constellations". Therefore, there is already quite a bit of group and teamwork in the current EDIT curricula, but there is still a lack of knowledge and reflection related to this area. This lack of explicit group competences sometimes leads to unsolvable conflicts, wrecked projects or delayed project deliveries. As a result students may feel excluded and supervisors powerless. By providing increased knowledge, reflection and understanding of group processes, team roles, values and conflict management and on how to use the group as a resource, we will create better opportunities for delivering project results on time with high quality. In addition, we will contribute to the students feeling a sense of belonging and to conflicts being prevented; thus, freeing up valuable supervision time.

By increasing the inner knowledge, i.e. increasing the knowledge of what is important for me, how I cooperate, what roles I take, what is hindering me, I will increase my outer ability to act well in a group. This leads to higher self-esteem, better collaboration ability and fewer unsolvable conflicts.

In the **Leadership** section the idea is to further nurture and develop the reflection the student made about herself and her way of being and reacting. Good leadership is basically about learning to lead yourself, knowing who you are, being clear, having the necessary courage and integrity, knowing your values and making decisions based on faith and trust instead of using fear as a driver. Our students will also be given a better position to become leaders if they have an opportunity to develop their personal leadership. Exercising leadership in different ways, for example by being the leader of a student work group (e.g. Supplemental instruction) or being a mentor for a group of newly admitted students, enables the student to try out leadership theories in practice which increase her self-knowledge through reflection and feedback. To this real-world experience theories of leadership, humanity, communication, conflict management and feedback are added.

The idea behind the **Career & professional life** section is that the students will be motivated and feel that they have made the correct choice by having a better picture what the future entails. A mentor program and a career-counseling course with an increased reflection of who I am, what I know and what I want, together with increased involvement of professional engineers in the first year of study are pieces that will help the student to feel that they have made the right choice and that they fit in. An increased insight into the professional life as an engineer and an increased self-awareness also helps students to deal with the various choices that the students have to make during their education.

We believe that "introspective knowledge gives extrovert ability" and that the increased self-awareness resulting from reflection and increased focus on personal development results in increased motivation, higher academic performance and better cooperation ability. Therefore, a **self-insight through reflection** package that helps students to identify and reflect on their development is introduced in our model. For the reflection to happen, students need to devote time to the process, get reflective questions that raise awareness about themselves and receive feedback on their behavior. It is through this increased self-knowledge that the opportunity is created to turn passive knowledge into valuable experiences that provide insight and power and motivation for change.

Pedagogical, as well as psychological, literature emphasizes the importance of reflection, dialog and feedback for personal development and learning. Also, from our own experiences in counseling and coaching we know that people develop and gain insights when responding to reflective questions that broaden and deepen the perspective and that offer the opportunity to try new behaviors. Therefore, a cornerstone of this model is that personal development takes place and is accelerated through dialog and reflection.

3.2 Curriculum Implementation

In our proposed curricula the focus shifts over time among these four topics, from motivation and learning in the beginning of the programs towards professional life and career at the end of the programs. Thus, thinking in terms of progression is important. An outline of a possible sequence for a bachelor program is illustrated in figure 3. When the sequence model shown in figure 3 is developed in more detail, different topics can be identified as indicated in figure 4.

Some examples of learning outcomes of the proposed personal-development package at the curriculum level could be that after completion of program the student should be able to:

- Set, understand and use her own goals, motivation and driving forces
- Use her self-knowledge for strengthening her external ability
- Work together in teams and understand how a group develops
- Reflect on professional roles, professional life and career planning

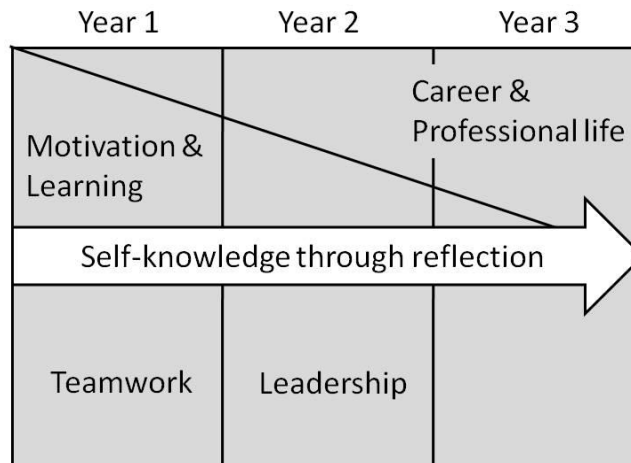


Figure 3. Major elements of EDIT personal-development model shown as a possible sequence for the bachelor part of a 5-year engineering program.

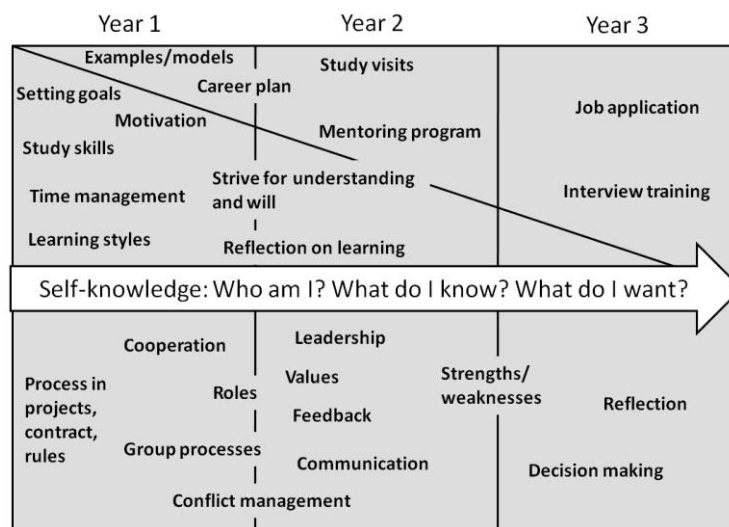


Figure 4. Elements of EDIT personal-development model laid out in a possible learning sequence for the bachelor part of a 5-year engineering program.

Based on the on theories of Lenn er Axelson, Thylefors and S lj  we argue that the learning should take place in interaction with fellow students and that self-reflection should be used as the learning method [8, 9]. We believe that personal development is a subject where learning by doing is a must and it is therefore obvious that constructive alignment should be used in the implementation of personal development. An example of personal development elements in a program curriculum is illustrated in Table 1.

Course-level Implementation

As stated above we believe that personal-development elements must be integrated in the program curriculum at times and in contexts that make them meaningful to the students. Still there are some options on how to do this. One way is to add elements into some **existing courses** and let the present teachers teach them, possibly supported by some consultant input. Another way is to create a **separate course** that runs over three years dealing with engineering skills which are assessed separately from other courses but which could be linked to parallel courses whenever possible. A third way is to introduce personal

development by adding **reflective elements in every course**. All courses will then have an ongoing parallel track containing reflective elements of personal development, where the student learns about herself. This parallel track does not alter course content but adds a new dimension.

In an ideal world, we believe the proposal involving reflective elements in each course is the one that would achieve the best results, since it would involve all teachers and have an impact not only on the individual level but also at the organizational level. However, the project steering group has assessed this proposal as impassable in the present situation.

Table 1
Example of personal development elements in a program curriculum

	Year 1	Year 2	Year 3
Program and/or group level	<ul style="list-style-type: none"> • Purpose and structure of educational program • Study skills • Goals / motivation • Group processes • Academic year wrap-up 	<ul style="list-style-type: none"> • Information – program tracks • Personal leadership • Attitude / values • Academic year wrap-up 	<ul style="list-style-type: none"> • Information – master programs • Culture clashes / conflict resolutions • CV/ personal letter • Academic year wrap-up
Individual level	<ul style="list-style-type: none"> • Learning style – what study strategy suits me? • Which role do I take in the group? • End-of-academic-year reflection 	<ul style="list-style-type: none"> • Which direction for me? • Action plan • End-of-academic-year reflection 	<ul style="list-style-type: none"> • Ethics / morals • Write my CV / personal letter • End-of-academic-year reflection
Job market	<ul style="list-style-type: none"> • Inspiration lectures • Alumni gathering – round-table discussions 	<ul style="list-style-type: none"> • Study visits / interviews with alumni 	<ul style="list-style-type: none"> • Mentors

The project's reference group has emphasized the importance of creating a system that is sustainable and independent of individual enthusiasts. In this respect, a separate course could be preferable, instead of integrating elements into too many courses, taught by teachers with a special interest in the issues. The reference group has also highlighted the risks of having too many integrated elements since it believes that this smearing out may increase the risk of personal development being regarded as less important.

We believe that there are advantages and disadvantages with the two remaining solutions. If the choice falls on integration, it is likely that the difficulties will be substantial to achieve the common understanding and starting point that are necessary for successful integration. If the choice falls on personal development as its own course, it must be designed so that it runs through the curriculum with small elements at several occasions. Personal development needs a longer time cycle to work. Such a course is extremely difficult to manage in practice.

Each program needs to find its appropriate mix of integration and their own course, since a successful implementation also depends on the availability of suitable, interested teachers and of other teachers' feedback on the ideas and that heads of program assess the feasibility of implementing the changes. A feasible solution would be to integrate main elements of personal development into a few courses with project or group-work elements where they would have a natural connection to professional engineering skills. In addition, optional elements could be placed outside of courses, e.g. inspiration lectures, alumni gatherings, mentors and end-of-the-year reflections. Regardless of the implementation model chosen it

will require an integration manager who has the responsibility for personal-development learning sequence within the program curriculum.

Who will do the teaching?

Another important implementation issue is who will teach elements of personal development. Should it be the current faculty, experts in personal development or are there other options?

The reference group of this project suggests that personal-development elements should be taught by persons with expertise in personal development and not by the engineering faculty. This is because the persons responsible for these elements must have knowledge about the development of this field. In this project period the student counselors who worked in this project have also taught these elements. The proposed content of personal development lies, with respect to subject and competence, close to the competence area of student counselors since at Chalmers they often have a behavioral-science background. A new more proactive, team-oriented and educational role for student counselors may emerge as a result of this project. However, all student counselors do not have the appropriate competence profile and will not feel comfortable working this way. Chalmers is currently implementing a new organizational structure in which counselors are centralized, which might bring greater opportunities for differentiated roles. However, since personal-development elements probably will be integrated into existing courses a close cooperation with faculty is also necessary why an organizational structure closer to the faculty enabling this collaboration and interaction may be desirable.

4. THE EDIT MODEL IN CONTEXT

Both in the context of Chalmers Vision, Goals and Strategies [18], the Swedish Qualifications Ordinance [19] and the CDIO syllabus [4] the motivation for the introduction of personal development elements, as defined in the EDIT model, is strong.

The Qualifications Ordinance [19] for the five-year M.Sc. degree (*civilingenjörsexamen*) stipulates that upon completion the student should be able to

- demonstrate the ability to create, analyze and critically evaluate various technological solutions
- demonstrate the capacity for teamwork and collaboration with various constellations
- demonstrate the ability to identify the need for further knowledge and undertake ongoing development of his or her skills

Thus, from a program-outcome perspective, there is support for the introduction of educational elements covering motivation and learning as well as group dynamics and leadership.

The Bologna process has three overall objectives, one of which is to promote graduate employability [20]. To graduate engineers who are better prepared for today's professional life, should therefore be a good reason for introducing new elements addressing career and professional life in education.

Also, the CDIO syllabus provides support for many different types of engineering skills topics such as

- 2.4.5. Awareness of One's Personal Knowledge, Skills, and Attitudes
- 2.5.1. Professional Ethics, Integrity, Responsibility and Accountability
- 2.5.2. Professional Behavior

- 2.5.3. Proactively Planning for One's Career
- 3.1.1. Forming Effective Teams
- 3.1.2. Team Operation
- 3.1.3. Team Growth and Evolution
- 3.1.4. Leadership

all of which are within the framework of the EDIT model of personal development.

Also the Chalmers Vision, Goals and Strategies 2008-2015, supports personal development: "Chalmers' educational programs focus on the individual's development with supervision, problem-solving, industrial and research contact, sustainable development and reality-based leadership.", [18].

Moreover, personal development, according to our definition, fits very well within the ideas of constructive alignment as self-awareness and personal development is achieved in active forms of teaching enabling reflection, that is student-centered learning [3].

After a short survey of engineering program curricula within Chalmers and other Swedish technical universities, we have not been able to find any course or identified learning sequence having content and process according to our definition of personal development. Nor have we have found anyone taking the overall approach to personal development that we have chosen to do. However, elements of what we define as personal development can be found in courses or as other optional elements offered elsewhere. These can be found in courses having titles such as: Appreciated leadership [21]; Work organization [22]; Communication and professional development [23]; Dialogue, coaching and personal development [24] and Qualifications' portfolio [25]. Our reflection, after having studied these and other courses, is that it seems difficult to get courses of this kind to work as intended and that they remarkably often seems to be closed down or cancelled. Why then do we think that we should be able to get it to work at Chalmers? First of all we think that the time now has come for personal development and all the Heads of the EDIT programs are positive to these ideas. Then, students and many (but not all) teachers realize the needs and are positive, maybe due to the influences from the CDIO syllabus and the ideas of constructive alignment. Also external motivators such as the emphasis on professional skills in the Swedish Qualifications Ordinance and requests from employers may play an important role.

5. EXPERIENCES FROM THE EDIT-MODEL IMPLEMENTATION

During the project period, we have tested several elements of personal development. These elements have mainly been related to motivation & learning, teamwork and career & professional life and have been taught by the student counselors involved in this project (the three first authors). Table 2 gives an overview of what has been done.

5.1 How to Set Goals

In the beginning of the fall semester an introductory lecture was offered to new students aiming at introducing them to the concepts of setting goals, motivation and taking responsibility and to start a process that clarifies the student's own responsibility. Attendance was not compulsory, but almost all students participated, possibly explained by the fact that presence usually is high in the beginning of the fall semester. No formal evaluation was done, but an oral evaluation showed that the students appreciated the lecture. For our side, it was an attempt to provide inspiration early and make it clear that students need a goal and a willingness to take personal responsibility for their goals and their future. Many students find

it difficult to set goals and the lecture gave an initial platform for continued work on goals and accountability.

5.2 Training in Setting Goals and Making Plans

Later during the fall, we held group discussions with the new students. The purpose of these discussions was to raise the students' awareness on how to set their own goals, make action plans to achieve their goals and to start the thinking processes on their own driving forces and responsibilities. No formal evaluation was performed but an oral evaluation showed that also in this case the appreciated the lecture. We noticed during counseling talks that more students than previous years had the need to discuss if they have chosen the right education and if they have sufficient motivation and incentive to study. From our point of view, it is positive that these thoughts arise early in the education when the student has not invested as much as energy, time and money in an education that may not suit him.

Table 2

An overview of elements of personal development that have been tested during 2010 in the Electrical, Computer and Software Engineering programs.

	Lecture	Workshop	Group disc.	Other	EE program	CE program	SE program	Integrated	Elective	Evaluation comments
How to set goals	X				X	X	X		X	Has not been formally evaluated. An oral evaluation shows that the lectures were appreciated.
Training in setting goals and making plans			X			X	X		X	Has not been evaluated. An oral evaluation shows that the elements were appreciated.
Study skills		X				X	X		X	Students appreciate exercises, inspiration and exchange of experiences during the workshop.
Introducing group dynamics	X				X		X	X		SE students requested also conflict management elements. EE students said that the content was relevant and of appropriate extent.
Exercises and reflection on teamwork and group dynamics		X			X			X		45 % of respondents considered exercises and lectures to some, large or very large extent contributed to improving the cooperation in the group.
GET SET™ Belbin's group roll test				X	X			X		Has not been evaluated.
Mentoring program				X	X	X	X		X	All participants express satisfaction. Students have established an important industrial contact and have become more self-confident on what they want and where they are heading.
Career planning course				X			X	X		Most students appreciate the course very much and believe that it is useful for them.

5.3 Study Skills

For the last 5-10 years, two lectures on study skills, given by an external expert, have been offered to the new students. Evaluations from previous years show that the students appreciate the lectures, but they are not inspired enough to act and really change their own study habits or behaviors. This year, we added two workshops as a complement. In these workshops, students make inventories of their own study habits and test new ideas to create their own active study strategies and methods based on ideas provided in the lectures. An evaluation of the workshops shows that the participating students appreciated the exercises, the inspiration and the sharing of experiences. According to the students, the workshops give results and act as an eye-opener to what you do and do not do in reality. As an improvement of the workshops the students suggest more sessions and further discussions among themselves.

5.4 Introduction to Group Dynamics

To introduce group dynamics, we have conducted lectures in the first and second years of the Electrical engineering program and in the first year of the Software engineering program. The objective has been to provide students with knowledge of the process of a project, knowledge of group development and to provide some practical tools for effective cooperation. Course evaluations show that software-engineering students want more group dynamics where feedback and conflict management are included. First-year electrical-engineering students perceived lectures and exercises as relevant, interesting and as being of appropriate extent. Second-year electrical-engineering students appreciate the lecture dealing with teamwork and said that it contributed to an increased enthusiasm in the beginning of the course.

5.5 Workshops in Group Dynamics

Also, in the first-year project course, the electrical-engineering students have been offered workshops on group dynamics on two occasions. In these workshops students have reflected on and discussed how their project group functioned. They have also participated in various exercises aimed at strengthening them as group members and have received feedback from their project-group members aimed at increasing their self-knowledge. The course evaluation showed that the lectures and exercises on group dynamics are perceived as moderately comprehensive, relevant and interesting. Even though 55 % of the students answered that these elements only to a small extent contributed to their group working well, from the comments in the evaluation we conclude that most of the students thought that their own group worked well. Of the responding students 34 % answered that group dynamic elements to some extent contributed to the group working well, while 6 % said it contributed to a great extent and 3 % said these elements did not contribute very much. One problem was that those students who needed these exercises the most did not attend, which rendered some exercises less meaningful, because the most affected groups did not get receive much instructor-led collaborative discussions.

5.6 Team Role Test

Students in the Master program in Integrated Electronic System Design have, in connection with a project course, been offered to participate in the commercial GET SET™ Team Role Test by Belbin [24, 25]. The test is based on Meredith Belbin's research on the nine team roles in successful teams [24, 25]. The test contains a number of questions that both the student and a number of persons that student has chosen herself should answer. The test report obtained includes results that both related to the individual and the project group of which the student is a member. The aim of the study is to provide greater self-awareness and to provide a picture of the strengths and weaknesses of the project group. In principle, all

students participated in the test, but all did not want to participate in the evaluation of it. We also performed the test ourselves within this personal development project and our opinion is that you can have good use of it both as an individual as member of a group team. The test results were strikingly positive in nature and had a focus on strengths rather than weaknesses.

5.7 Career course

In the project period we have also led the career course in the Software engineering program. Experience from the course show the importance of having exercises and questions that make the students reflect on themselves and where they are heading. Furthermore, for us, leading the course, it became clear that it is not easy to teach a course developed in detail by another teacher. Our conclusion from this experience is that the details of a course must be tweaked by the teachers and team leader who are to lead the course. The evaluation of the course show that it is much appreciated and that most students feel that their self-awareness has increased and that they have become clearer about what they want. A few answer that they do not appreciate the course (which is mandatory). Most students believe that they will benefit from this course.

5.8 Mentoring Program

Jointly with *Svenska Elektro- och Dataingenjörers Riksförening (SER)*, we have also started up MEDIT, the mentoring program for fourth-year students in the EDIT programs. During the year, 23 students have each had a mentor from industry. One objective of the mentoring program is that it will contribute both to the students' personal and professional development. The program evaluation shows that both students and mentors are very satisfied with the mentoring program. For the students the program has led to an important contact with industry and that it has become clearer with what they want and where they are going.

5.9 Learning Outcomes

In our project we have aimed at formulating and introducing learning outcomes for personal development in courses where these elements are to be integrated.

An example from the EE program is the first-semester project-based introductory course "Technical communication" where learning outcomes related to group dynamics have been introduced in the syllabus for the academic year 2011/2012. After completion of the course the student should be able to

- Identify and apply methods for effectively working in a group
- Develop routines for continuously reflecting over the project work
- Work in a group and take responsibility for the project's completion
- Work with both the project's contents and process
- Create and use group norms
- Relate to personal values and how these affect the teamwork.
- Identify and apply methods for effectively working in a group

Thus, we are now clear in that one of the main objectives for the course is to practice teamwork, something that was previously unclear for both students and teacher, when most of the attention was paid to the content rather than to the process. Also, the learning outcomes of the course "Communication and professional development" in the SE program have been re-worked. There are on-going discussions in the CE program on introducing learning outcomes related to personal development into the course "Sustainable use of resources".

So far, we have focused on introducing learning outcomes related to personal development in first-year courses, but our intention is to continue with courses in later years. Thus, the end result will be a learning sequence.

6. DISCUSSION

In conclusion, our experiences from our test in introducing elements of personal development, is that these elements generally are appreciated by the students. However, we have also evoked processes in the minds of some students that we must be prepared to take care of individually. We argue that it is important that students process these questions and get clarity in their motivation early in their education. It is worse if these doubts come later when they might have lagged behind in their studies.

An essential but difficult issue to address is how to assess the effect of introduced personal development elements. Key figures that could possibly be used as indicators, and which are measured annually, are pass rates on course level and the average number of credits scored per student after one year. However, these numbers vary over the years depending on external factors such as the admitted students' high-school GPA making the comparison of successive cohorts in the same program questionable. Comparison between programs the same year is even more fraught with problems since there are many additional factors that vary. Therefore, we suggest the use of qualitative approaches, for example one could follow the students' development through structured interviews and through reflective discussions either individually or in groups. An in-depth interview could be performed as an exit talk upon completion of the bachelor level. Possibly the attention paid to the students in this approach in itself will improve the perception of the students such that they feel more motivated and put a greater effort in the studies.

When we have tested group dynamics in the Electrical engineering program, we have noted that students are more satisfied with the cooperation in their project groups and they have reached further than usual at this stage in group development. In addition, the group members are in better agreement about the goals of the projects than is normally the case at this stage. The examiner of the course is positive about that we, the student counselors, have been responsible for the elements of personal development, since we were able to adapt the contents to the need of the students. Our experience is that the content should not be too theoretical or delivered too much as lectures. Students request tools, not lectures, on group psychology.

In interviews students indicate that they are interested in developing themselves personally to feel self-satisfaction and to be more secure about the decisions they must take, but also that they want more contact with professional life, more leadership and group dynamics, communication, presentation, rhetoric and feedback.

The teachers emphasize the importance of implementing measures that help increasing pass rates. They also see benefits of working more with students' motivation and setting goals, to create conditions for both students and teachers to focus on the subject matter in projects and theses instead of handling problems of inter-human character. Furthermore, many teachers have pointed out that the subject matter itself in technical courses causes personal development of the students – however, the students have been less clear about this. Maybe we will have learning outcomes related to personal development in ALL courses eventually, but of different kinds!

Representatives from various professional roles, industries and businesses, argue that they want engineers with good self-awareness who know how to communicate, who can understand and interpret other people's behavior, who know active methods of teamwork and

who can deal professionally with conflicts. They also call for skills in documentation, communication and presentation, commercial awareness, time management and attitude of ethics and values.

7. CONCLUSIONS

Our hypothesis is that an increased focus on the student's personal development can contribute to increased motivation, better learning and higher quality of teamwork in the engineering program. We have elaborated and suggested the EDIT model for how personal development could be realized. Further development of the model and its implementation into the curriculum and how the results could be assessed is however still in progress. Also the question of who should teach these elements is currently being discussed at Chalmers in parallel with an ongoing organizational change.

What distinguishes the ideas behind personal development from conventional courses in these programs is that we mainly target the process, i.e. how to interpret and process the lectured content and how it is allowed to influence opinion or behavior. We believe that reflection on what the student experiences, accelerates her personal-development process, increases motivation and contributes to improved quality. By working systematically with reflective questions such as "What skills have I developed so far? How do I know that? What are my goals for next semester? What do I do to reach my goals? For what reasons do I take this course? What do I want to achieve with this course? What do I need to take responsibility for?" the student develops faster.

During this year, the first three authors, the study counselors, have also been recognized and used as a resource for teachers and tutors who have had project teams that functioned poorly. On such occasions we have noticed that teachers often lack the means and tools to deal with problems occurring between students. As the number of courses with project elements tend to increase, we draw the conclusion that there will be an increased need for support for teachers and tutors, particularly as part of the students who need help to manage work in groups, often choose not to participate in the optional elements offered.

This year we have noticed more early dropouts from the programs than previous years. We have had fewer problems in teamwork and we have had more students who wanted to discuss whether the educational choices they have made are right for them or not. If the observed changes are coincidences or are due to the efforts we have made is too early to conclude. If these effects persist, one conclusion to be drawn is that no matter how and who will be responsible for implementation, the university must be prepared to support some of the students individually, as personal development will start processes within individual students' minds.

The continued development and implementation depends on the interest of teachers, heads of educational programs, deans of education and administrative executives. The choice of teacher for personal development depends on if one chooses to develop the skills of student counselors or of the engineering faculty or possibly both. Either choice will require knowledge and establishment of a bond to the behavioral science field in order to achieve sufficient legitimacy.

We believe that an increased focus on the student's personal development will contribute to increased motivation, better learning and higher quality of teamwork in the engineering program, even though it is extremely hard to provide explicit evidence for this.

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MULTIDISCIPLINARY TEACHING – MSc COURSE ON TEAMWORK AND OPERATION

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ABSTRACT

Industrialization and technical development led to a split of the traditional role of the master builder into two: the architect and the engineer. Additionally, new demands on functionality such as energy and cost efficiency led to an increasing need of functioning collaboration in large teams during the design phase; as well as a need of new work methods within the process. This calls for employees who are experienced in collaborating in interdisciplinary teams. To fulfill this demand a multidisciplinary course in “Advanced building design” has been developed at the Technical University of Denmark. The goal of the course is to provide training in teamwork at the final stage of the engineering education. The course has been carried out twice. It was held by a multidisciplinary team of professors in periods 2008/09, 2009/10 and 2010/2011. Teams of students were subject of a questionnaire investigation on collaboration and team work. The study has the following findings. The latest year there has been a special focus on team work and all members tested their role according to Belbin’s theory on teamwork. The work has the following findings: Collaboration was generally good. However the extra focus on teamwork did not lead to a improvement of the team work in contrary. The team-structure was generally flat and decisions were mostly made in consensus. It is worthwhile to offer a multidisciplinary course and give engineering students experience in collaboration methods.

KEYWORDS

Building design, collaboration, architect, engineer.

INTRODUCTION

Since the industrialisation of the construction industry and before the technical development the master builder [1] have been replaced with architects and engineers [2]. Due to a massive technical development the role of the engineer has become increasingly more important. Engineers have specialized into different domains and are today dealing with structural design, services, foundations, indoor climate, construction management, facilities management, IT and CAD specialists, are educated to fill the demand [3]. The traditional collaboration of the partners in a building process requires a minimum of team work [4], and lean principles and logistics are rarely applied to the process. The collaboration between architects and engineers is described by Weingardt [5] as “difficult”, “turf battle” and being “warring cells”. There is a great risk of miscollaboration in the initial stages of a project which have been identified by McCluren [6]. A malfunction of the teams has been pointed out due to a lack of insight into other professions [6], [7]. Some engineers like Ove Arup and P Rice decided to work closely with architects with varying level of success while P L Nervi and Eudardo Torroja decided to exclude the architects from their work [8]. The existing way of

collaboration have demonstrated its weaknesses in many projects and led to new way of organizing projects. One of them is partnering being an organization form turning into a collaboration method at a later stage of the process [9]. In some cases the method was cost saving [5] in others this type of alliances were negatively affected by competitive forces, overlap of the subprojects and lack of trust [8] [9][9]. Integrated Project Delivery (IPD) is a different approach that involving owner, architects, engineers, , and the contractors or builders as the core group to manage an integrated project delivery process [11]. Building Information Modeling (BIM) is used as a digital representation of a building to facilitate exchange and interoperability of information in digital format". BIM aims at improving the communication between parties.

At Technical University of Denmark a course for MSc. tries to both introduce the students to projects that can be compared with projects from the industry and introduced to the use of BIM. The students have to work within a given domain and development of collaboration has been studied for three years [14], [15]. The background for the course is based on the facts identified during seminar at the Technical University of Denmark with representatives from the industry [12][13]. The need for specialization but also collaboration abilities was expressed at the seminars in 2005 and 2007. In 2007 centre leader Simon Guy Marc from Manchester University expressed the "Need for creative workers trained in interdisciplinary and collaborative working". Besides professionalism and specialization the attendants of the DTU-avtagerseminar 2005 is was expressed that the engineer student's ability to "constructively collaborate in such as partnering and lean construction." have to be trained.

METHOD

The present statistical study is performed within a project oriented course. The task of the course is to plan a high rise office building in multidisciplinary teams. The students are expected to transform their knowledge into a building design by the group as a teamwork effort. It is the aim to enable the students a good start working in industry, by providing experiences about multidisciplinary design. The course is targets MSc. Architectural Engineering or Civil Engineering students, which already have a Bachelor degree. The professors were mostly trained as engineers. The course was given to the students for the first time in 08/09 and was mandatory for MSc. Architectural Engineering and Civil engineering students that year. The course was not mandatory the second and third time (09/10 and 10/11), but anyway difficult to avoid. Six different subjects were identified to represent different roles in a construction project. The six subjects were: Design (including fire strategy in 09/10), Structural (including structural fire safety), Building Services (energy), Soil and Water mechanics, Urban planning/ Construction Management/ Facility Management, and ICT Coordinator (and fire strategy in 10/11) . For each subject one or more professors were identified, and one or two students were given the role specified by the subject in each team. During the 13 week period autumn one morning weekly was reserved to the course. In total the workload for a 10 ECTS course at DTU is 280 hours. The students meet either in a subject group or together with the rest of the members of the team to a team session. The subject professors were present at groups meetings, while the team meetings were meant to be carried out without assistance from professors.

The goal of the present work is to study the change of collaboration over time and how collaboration is perceived in general as well as the structure of this type of teams. This is done developing a questionnaire which was answered in the years 08/09,, 09/10 and 10/11. The conditions for the course in the three periods are described below. **Conditions for period 08/09:** 67 students attended the course, and they were distributed into 9 teams. The course was led by a professor team with 15 members. 32 students (48%) and 7 (47%) of the professors took part in the questionnaire providing the results for the present study. **Conditions for period 09/10:** In periods 09/10 100 students registered the course. They were divided placed into 16 teams with 5 or 6 members. 67 students (67%) and 6 (60%) of the professors took part in the questionnaire. **Conditions for period 10/11:** In periods 10/11 allmost 100 students registered the course. They were divided placed into 13 teams with 5 or

6 members. 40 students (44%) took part in the questionnaire. In the first period the student and the professor teams have similar conditions, They were multidisciplinary, the participants did not explicitly choose to collaborate; no one could be excluded from the teams, there were tight deadlines and a high workload. All students were asked to answer the questionnaire. Students were given a standard- and course specific questionnaire including the possibility for making individual notes by the end of the course. In 10/11 the students were asked if they found a Belbin [16] self test useful. The current study is based on results originating from the three times the course has been conducted. Since the students are still studying at the university, it has not been possible to prove that the students have better qualifications in the given areas than students which have not followed the course. Hence, the outcome of the study can only give information on the short term development of a rather homogeneous group. Long term effects on collaboration of this teaching method could not be studied. However, such a course offers a base suitable for such an investigation since the students present a homogenous group of people, with similar background and age.

RESULTS AND DISCUSSION

The results discussed here deal with aspects of collaboration and team structure, based on the questionnaire and comments from the participating students of the three years.

The first two figures describe the collaboration. Figure 1 displays the answers to the question on how the collaboration the teams was experienced towards the end of the course. It can be seen that the collaboration was predominantly positive. However, in average 9% of the participants experienced a bad or very bad collaboration in their team. It can also be seen that the collaboration in year 2011 has a rather flat distribution compared to the previous years. Here the collaboration was experienced worst compared to the years 2009 and 2010. The question raises how this results is related to the extra focus on collaboration and team work in year 2011, where lectures on Belbin's theory on teamwork [16], Johari window [17] and solving conflict by nonviolent communication [18] were introduced.

Figure 2 shows how the collaboration in this multidisciplinary course was experienced compared to other projects and courses. Here it can be seen that the collaboration in all years was not experienced to be easy compared to other courses/projects. It can also be seen that most students express that the collaboration was difficult in 2011 than the previous years.

The strategies for problem solving used in the teams were mostly consensus as shown in Figure 3. In all three years only few students experienced that the decision making process was steered from the top or by vote.

A majority of students in year 2011 thought that the use of Belbin profiles was useless, as displayed in Figure 4. This question was new for 2011, where the team work was extra stressed and Belbin roles were introduced and applied. None of the students found that the application of the Belbin profile was very useful.

In spite of the difficulties experienced by many students a majority of the students found that the course is a good introduction to designing a realistic multidisciplinary construction project, as shown in Figure 5.

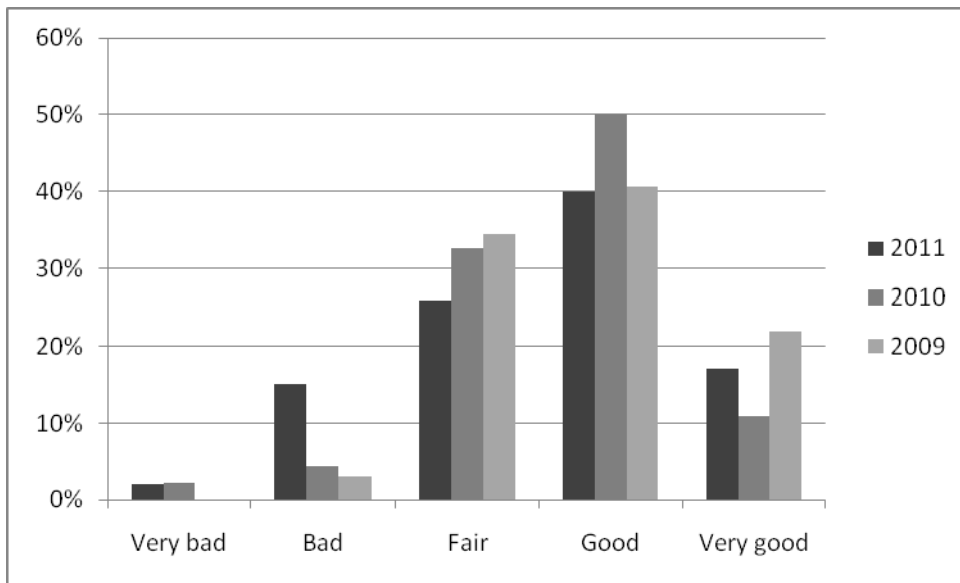


Figure 1: The collaboration of my team was:

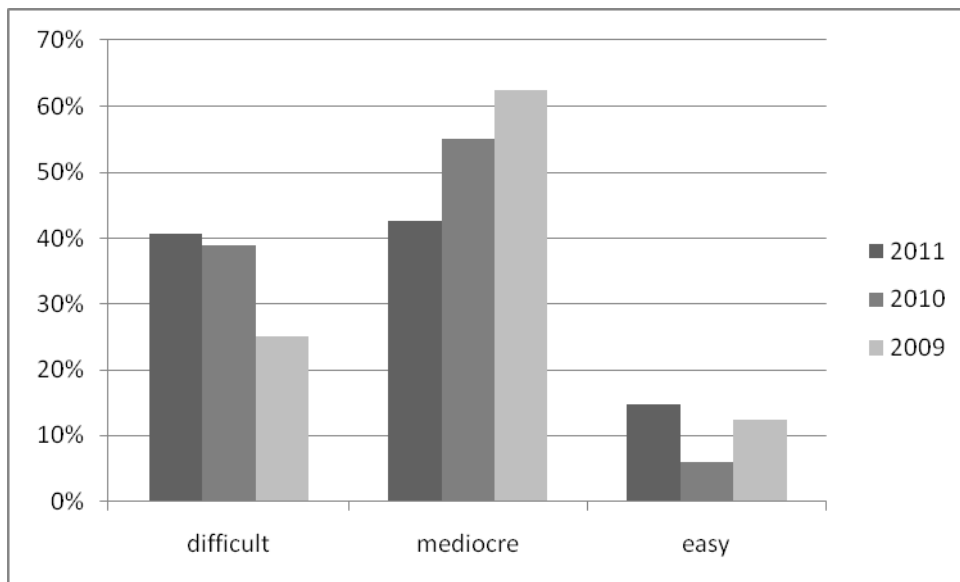


Figure 2: Compared with earlier courses/projects the collaboration was:

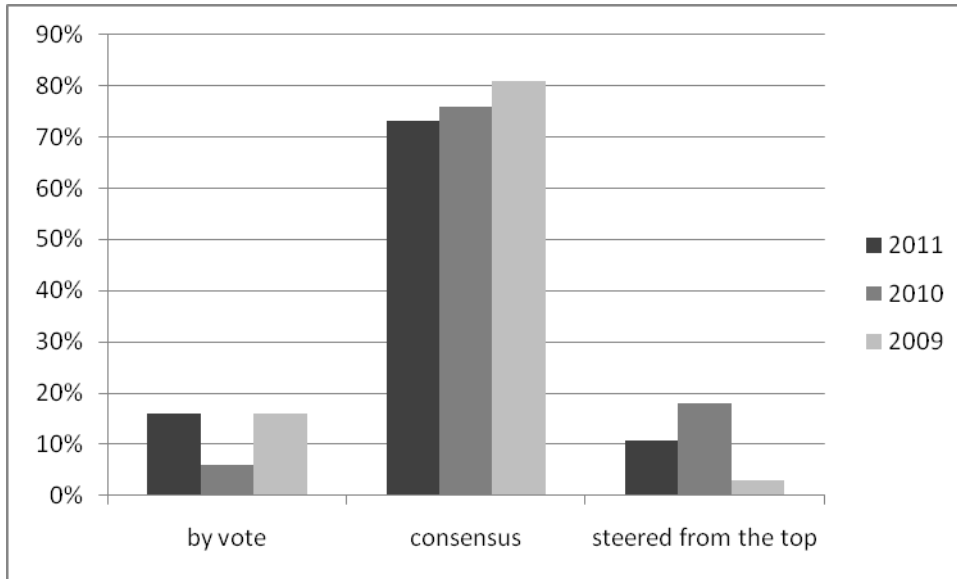


Figure 3: My team used one of the following strategies for problem solving:

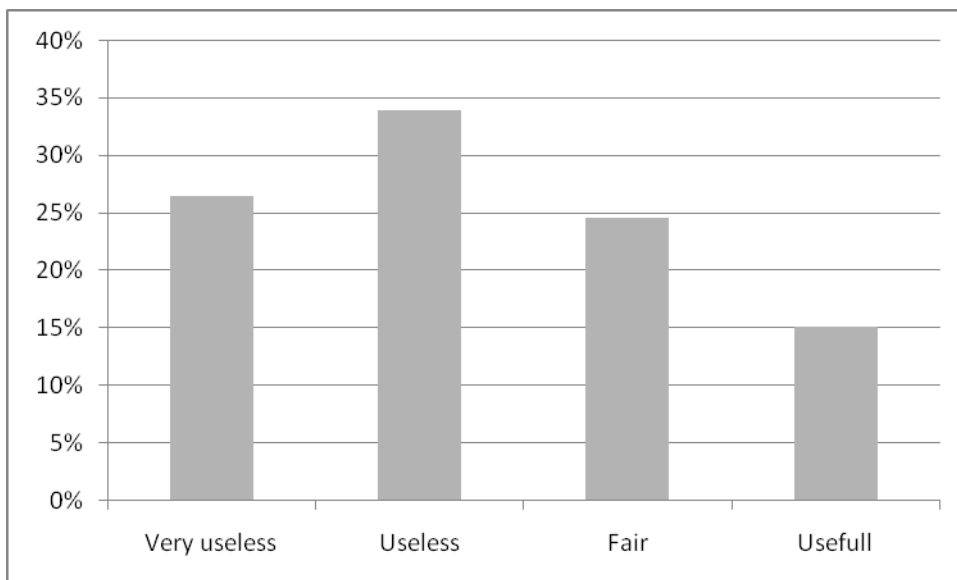


Figure 4: The use of Belbin profile analysis was:

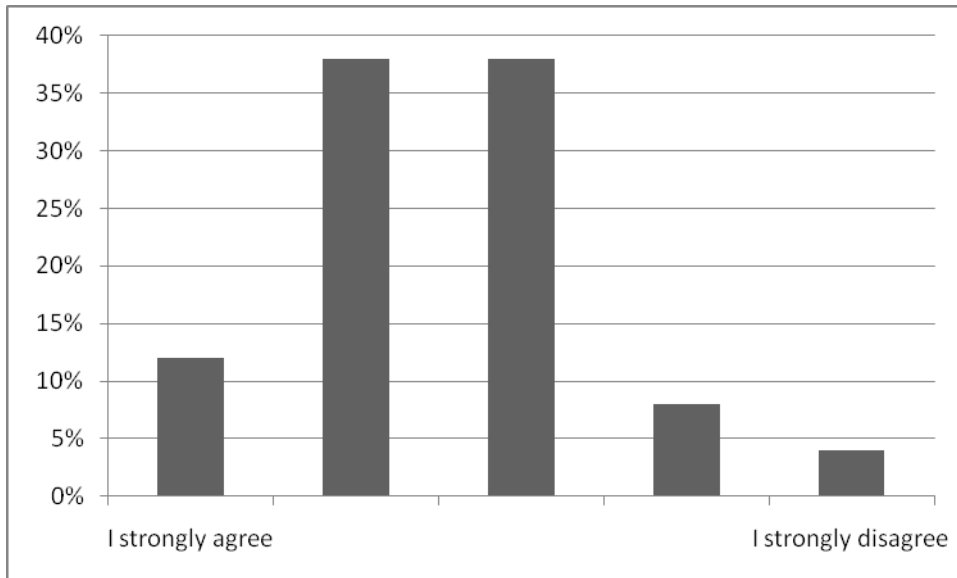


Figure 5: The course is a good introduction to designing a realistic multidisciplinary construction project

Based on the comments in the ordinary questionnaire all students receive it was clear that the teamwork aspect in the course had been a challenge. This led to the conclusion for some students that despite the challenge of making a fruitful teamwork, the course had been a good experience while others saw the course as something they rather would have been without. During spring 2010 a number of students were invited to be interviewed by the authors of this paper. Even though a limited number of students were interviewed and their view not may representative, it was clear that the atmospheres in their teams have had significant impact on the level of integration between the technical systems in the building. There may therefore be a direct relationship between teamwork in a team and the quality of the designed solution, this may not be a big surprise but nevertheless this can only encourage professors and managers to be aware of this aspect in order to make a good technical solution.

Based on experiences from the students it was decided to include lectures on teamwork for all students taking part in the course in 10/11 because implementing good teamwork in a team not can be dedicated to one member of a team.

CONCLUSION

The current work presents the results of a questionnaire study on collaboration and teamwork on the homogeneous population within a course run in 08/09 and 09/10 at the department of Civil Engineering at the Technical University of Denmark. Students and professors answered a questionnaire, which resulted in the following findings: collaboration was improved during the course in both periods. Initially collaboration was experienced more problematic than towards the end, confirming the statement by McCluren [7]. This statement is even strengthened by the result that collaboration was perceived better in retrospective. Furthermore the students and professors in both periods expressed that they learned on collaboration. During the first period the team leader in the student team was defined by the professors. The role of team leader was integrated in the role of the design manager and most teams followed this suggestion however a large fraction 17-18% picked the leader among the design students (which is the role traditionally taken). During the second period the students were free to choose their team leader. The leader came not from a specific subject, but was chosen according to other criteria not established in this investigation. The criteria may be individual characteristics. For both periods the team structure was generally flat and decisions were mostly made in consensus. For the next semester, the course is further developed, task descriptions are improved and the importance of team work and

collaboration methods will be stressed in the first weeks. A larger focus is placed on initial team building process.

Multidisciplinary teaching methods are essential any engineering education. Sustainable change in collaboration in the design process should be induced at Universities. In order to support such a change in industry students should be exposed to team work that differs from the traditional one.

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AN INNOVATIVE APPROACH TO DEVELOP STUDENTS' INDUSTRIAL PROBLEM SOLVING SKILLS

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ABSTRACT

This paper presents details of the multi-disciplinary capstone course 'Advanced Innovation and New Product Development', which was developed by the INNOVATIONZ research group at the University of Auckland, New Zealand. The course is run in collaboration with the University's Business and Creative Arts faculties, and with a range of industry partners, design consultants and business professionals, and is aimed at providing Engineering students with practice-relevant and multi-disciplinary learning experiences in the areas of product design, new product development and innovation management. The course includes a number of features and approaches which create a rich and integrated learning environment that helps students develop interdisciplinary product development knowledge, practise their teamwork and communication skills, and experience the new product development process through real-life project work.

In the paper we provide an overview of the general concept and structure of our course, including course philosophy, course design and course objectives, which are in line with the needs of industry and with the requirements of the Engineering profession. This is followed by a more detailed discussion of a number of key aspects of our approach, which are particularly relevant to the achievement of our course objectives and outcomes. The main areas we discuss are our project-based learning approach and the associated assessment procedures, which are designed to support those aspects of learning we find particularly relevant for our students. Another important aspect covered in the paper is our approach to fostering the development of multi-disciplinary teamwork skills, which are critical for the successful involvement of professional engineers in the product development process. We conclude the paper with a selection of feedback comments from our students, which illustrate the effectiveness and the educational value of our course.

KEYWORDS

Project-based learning, new product development, multi-disciplinary teamwork, assessment, reflections on learning

INTRODUCTION

To maintain their competitiveness in the globalised economy, manufacturing companies must develop their capability to continually design and produce innovative products that are cost-competitive and exceed or at least meet their customers' expectations. However, the design of new products, and in particular of those which require significant technology or engineering development, is challenging as truly innovative products need to be optimised with respect to a broad range of criteria: Apart from offering intuitive and flawless technical functionality, they need to be aesthetically pleasing, reliable, cost-competitive, and include particular attributes and features that set them apart from their competitors and lead to a superior customer experience.

The design and development of such products requires a New Product Development (NPD) process which includes inputs from a diverse range of perspectives. Successful NPD in the competitive global marketplace depends vitally on synergies between a broad spectrum of disciplines such as engineering design, industrial and graphic design, technology management, business innovation, change management, branding and marketing. Generating and maintaining a creative and synergistic NPD environment and culture is a key challenge for manufacturing organisations; and it is particularly important for them that their design staff have sound professional backgrounds in areas like engineering, manufacturing and design, but also possess multidisciplinary skills and experience, and are capable of playing an integrative role in a creative design-driven business environment.

The NPD process is particularly challenging for Small and Medium Sized Enterprises (SMEs), which often do not have adequate resources and sufficiently competent and experienced staff in this area. This problem has been widely recognised in the last few years, and there have been a range of international programmes and initiatives that are aimed at fostering product innovation in SMEs, for example the European Small Business Portal [1] and the EUREKA Eurostars programme by the European Union [2].

Background of Approach

New Zealand (NZ) is an economy dominated by SMEs which operate in a small domestic market. Many of the country's small manufacturers depend on exports for their survival, and therefore need to be innovative to thrive and compete in global markets. However, it is widely accepted that NZ manufacturing SMEs must improve their NPD capability in order to enhance their ability to compete internationally. Recognizing the importance of these issues, the New Zealand Government commissioned a major study in 2003 into the role of design for the economy [3], which concluded that design was under-used in the vast majority of local SMEs, and that there was a widespread lack of relevant competencies and skills in this area.

The NZ Government funded project 'High Technology Design for Engineering Product Innovation', which evolved into the INNOVATIONZ research group [4] at the Department of Mechanical Engineering at the University of Auckland, was aimed at enhancing tertiary design education in all areas of Engineering, as well as in the Business and the Creative Arts Faculties at the University of Auckland. Its overall goal was to achieve a closer match between human resource requirements in the areas of engineering design, innovation management and new product development of New Zealand's manufacturing SMEs, and the skill profiles of future engineering and other university graduates.

The project's focus was on providing engineering students from the University of Auckland, as well as industry practitioners and students from other faculties, with high-quality, practice-relevant and multi-disciplinary learning experiences in the areas of product design, NPD and innovation management. At the same time a postgraduate programme and a professional development framework for design engineers and other design practitioners from the industry sector were established that cater to their specific training needs, reflect the requirements of professional bodies and industry training organisations, and are closely integrated with the academic curriculum [5].

Emphasis was placed on a holistic and multi-disciplinary approach that integrates academic and educational perspectives with the skill profiles and practical requirements of professional design engineers and other design professionals, as well as with the strategic human capital development objectives of the industry. The implementation of these principles was a significant departure from the traditional, discipline-based teaching system, and required the integration and concurrent consideration of aspects and disciplines from outside the traditional engineering domain, such as industrial design, marketing, branding and innovation management, but also the incorporation of 'soft' topics such as teamwork and cross-disciplinary communication.

A core element of this development is the course ENGGEN 405 'Advanced Innovation and New Product Development', which was established in 2006 in collaboration with the University's Business and Creative Arts faculties, and with a range of industry partners, design consultants and business professionals. The course has been used as the primary tool to develop, test and implement novel learning approaches, which enable students and participating industry partners to develop interdisciplinary product development knowledge, to practise their teamwork and communication skills, and to experience the NPD process through real-life case study work.

In this paper, some of the core aspects and features of the ENGGEN 405 course are discussed in more detail. In order to put this discussion into context, we first explore the role of professional engineers in NPD, and provide a brief overview of other educational programmes which are also aimed at preparing graduates for their roles in multi-disciplinary NPD process environments in industry.

We then introduce the general concept and structure of our course, including course philosophy, course design, course objectives and intended learning outcomes. After that we provide more details on a number of key aspects of our approach, which are particularly relevant to the achievement of these objectives and outcomes, and which are in line with the needs of industry and with the requirements of the Engineering profession. The main areas we discuss are our project-based learning practices and the associated assessment procedures, which are designed to support those aspects of learning we find particularly relevant and beneficial for our students. Another important aspect covered in the paper is

our approach to fostering the development of multi-disciplinary teamwork skills, which are critical for the successful involvement of professional engineers in the NPD process. Additional features of our course, in particular the studio sessions and associated workshops, which support and deepen the students' learning experience during their project work, are only briefly mentioned, as their detailed coverage would exceed the scope of this paper.

THE ROLE OF PROFESSIONAL ENGINEERS IN NPD

Professional engineers have always played an important role in NPD by contributing a broad range of traditional engineering skills and knowledge, for example from the areas of material science, mechanics, thermodynamics and manufacturing processes, into the process. In the last few decades, engineers have broadened their involvement in the NPD process with the advent of modern tools and approaches, such as Computer Aided Design (CAD), Finite Element Analysis (FEA), Concurrent Engineering, and other product and process modelling, optimisation and visualisation tools. These technological and organisational developments, together with the increasing competitive pressure discussed above, have fostered significant changes of the traditional tasks and skill requirements of professional engineers in the NPD process.

These developments have also influenced the demands made of engineering graduates by businesses that employ professional engineers, as well as by professional organisations like the Accreditation Board for Engineering and Technology (ABET), the Institution of Engineers, Australia (IEAust) and the Institution of Professional Engineers, New Zealand (IPENZ). Whilst a solid understanding of engineering science principles is still a fundamental expectation of modern graduate engineers, some of the most important requirements now are the ability to communicate effectively, the ability to work independently as well as in a team, and the ability to think both critically and creatively [6]. To achieve this, the ABET Criteria for Accrediting Engineering Programs require that engineering students "must be prepared for engineering practice through a curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints" [7], such as manufacturability, sustainability, and environmental, economic, political, social and ethical issues. Expected learning outcomes include the ability to function on multidisciplinary teams, the ability to communicate effectively, and the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context [7].

INTERNATIONAL NPD RELATED PROGRAMMES

There are a number of successful educational programmes offered internationally which have evolved as a response to the changed situation in the area of innovative product design and development. UK Universities offer majors at undergraduate and graduate level that combine creative design and engineering. Engineering schools such as The University of Strathclyde, The University of Nottingham, The University of Glasgow and The University of Wales (Swansea), among others, offer BEng or MEng programmes majoring in product design engineering. The Royal College of Arts (RCA) and Imperial University have offered a postgraduate programme in IDE (Industrial Design Engineering) since the 1980s. Cranfield

University and the University of Arts in London offer a Masters degree in Innovation and Creativity in Industry which is aimed at providing graduates with creative, technology and business skills. The UK majors combine innovation and creative thought with a strong background of engineering design and manufacturing. They produce graduates who are equipped for careers in design and manufacturing engineering, or product development. Many of the courses are accredited by professional bodies, such as the IMechE or the IET.

Other international programmes in the area of NPD include the University of Southern Denmark's BSc (Eng) in Product Design and Innovation, the University of Michigan's Integrated Product Development Programme, and Hong Kong Polytechnic University's programmes, which involve close cooperation with a range of academic and business partners. In Australia, the Swinburne Institute of Technology (Melbourne) offers a BE in Product Design Engineering. This is accredited by both Engineers Australia and the Design Institute of Australia. Graduates develop skills relevant to product design, engineering and manufacturing industries in Australia. The course blends the two usually distinct disciplines of industrial design and engineering.

In New Zealand, Massey University offers a full professional degree programme in product development. The Wellington Institute of Technology, Weltec, has launched a Bachelor of Creative Technologies degree. This offers a major in Product Design Engineering alongside majors in interior design, cultural design and visual arts. Otago Polytechnic offers the Bachelor of Design (Product). While this is a Design based major, it claims to offer more skills in engineering design and manufacture than other BDes majors. Otago University offers a major in Design for Technology as part of their BAppSc programme. The major targets aesthetic and technical design. It focuses on design, with elements of mathematics and science available as electives.

Most of these programmes are heavily project-driven, and the students learn through a series of increasingly complex problem-solving projects and supporting teaching. They are aimed at developing skills and experience which cross the traditional boundaries between the engineering, industrial design and business professions, generally in form of an integrated curriculum programme at undergraduate or graduate level.

Our ENGGEN 405 'Advanced Innovation and New Product Development' course has similar aims as these programmes. However, instead of attempting to educate future NPD specialists, our course aims to complement the existing undergraduate Engineering curriculum at the University of Auckland, by providing interested students with a multi-disciplinary capstone experience. Our target is to provide our students with a rich and meaningful, multi-disciplinary project experience which will enable them to accommodate easily and make positive contributions to a dynamic, commercial NPD environment, and which is also applicable in other areas of technology and innovation management in industry.

COURSE DETAILS AND LEARNING OBJECTIVES

As mentioned above, the course ENGGEN 405 'Advanced Innovation and New Product Development' aims to provide professional engineering graduates and senior students of other faculties of the University of Auckland with the knowledge and experience required to successfully apply their professional skills in today's multi-disciplinary NPD environments, which are so necessary for invigorating and maintaining innovation in the manufacturing

industry. The course design evolved over a period of several years, and was strongly influenced by the authors' multi-disciplinary academic and professional backgrounds, and by their practical experience with industry based project work and with Project Based Learning (PBL) in undergraduate engineering design, manufacturing systems and technology management courses [8, 9].

The course approach is also based on a number of pedagogical principles which are in line with the educational theories of David Perkins, for example on 'learning for understanding' [10,11], and with the work of Donald Schön and Chris Argyris on learning systems, learning societies and institutions, double-loop and organisational learning [12, 13].

From the start, the course has been based on a multitude of collaborative activities and partnerships across disciplinary, faculty and institutional boundaries. Within the University of Auckland, this boundary-spanning approach involved in particular the close relationships between staff in the Faculty of Engineering, the Business School, NICAI, the University's National Institute of Creative Arts and Industries, and also in a number of instances the Faculties of Education, Arts, and Science, and the Centre for Academic Development. External links were fostered with various professional bodies in engineering, design and business, for example the New Zealand Employers and Manufacturers Association (EMA), the New Zealand Heavy Engineering Research Association (HERA), the Designers Institute of New Zealand (DINZ) and the local branch of the Product Development Management Association (PDMA). Particularly effective has been the direct involvement of six industry partners as host companies for our NPD projects, as well as of professionals from a range of disciplines, such as self-employed design and engineering consultants, business managers from a variety of backgrounds, and design and engineering practitioners from a range of positions and with various levels of professional experience. Links with other educational institutions, which had a positive impact on our educational activities, were fostered with Massey University and some NZ vocational training organisations. Most of these collaborative activities resulted not only in enhanced learning opportunities for the tertiary students involved in our coursework and associated project activities, but also in a two-way knowledge exchange by broadening and deepening the understanding of the participating professionals and managers.

Originally, the course Innovation and New Product Development was hosted by the University's Business School as an approved elective for Engineering students interested in innovation, until a concurrent parallel version was included in the Faculty of Engineering curriculum to account for the requirements of changed regulations of the BE(Hons) degree. At this stage, the course has been run six times with a variety of local manufacturing SMEs as project hosts, with around 200 students from Engineering and five other faculties of the University of Auckland graduating from the course.

In Engineering, ENGGEN 405 is advertised as a course for *"final year Engineering students, which deals with theoretical foundations and practical application of innovation, design processes, new product development and problem-solving within the commercial and cultural context of New Zealand businesses. Students from different backgrounds will be grouped into cross-functional project teams and will work on a real-life industry based project and develop a full product concept for a business client."* [14]

In line with the overall objectives and philosophy of the INNOVATIONZ research group, the course is aimed to introduce students to 'real-world' design problems, and to provide students with a solid understanding and hands-on experience of the New Product

Development (NPD) process by developing a product concept as a team. Engineering students who take the course are provided with opportunities to develop their communication, interpersonal and teamwork skills by working with other senior students from different disciplines and faculties, develop the technical skills and professional techniques that the industry needs, and will be equipped with a better understanding of the 'real world' issues of the industrial and business environment.

Upon completion of the course students are expected to have achieved the following learning objectives and will be able to:

- Present their proposed product concept in a professional fashion to a business client,
- Effectively identify and prioritise key areas for design development to achieve the best commercial outcome,
- Use practical and theoretical methodologies to communicate and evaluate product ideas,
- Apply creative processes and a structured, well-managed team approach for solving a complex product development task,
- Integrate perspectives from art and design, engineering and management,
- Use their practically acquired learning to make academic knowledge more valuable,
- Use new personal skills of teamwork with others from different disciplines,
- Demonstrate experience of working with an industry partner,
- Use effective contemporary professional techniques to ensure value for a real industry derived need.

Due to the multi-disciplinary nature of NPD, a broad range of topics are covered in the course (Figure 1), including:

- Principles and context of New Product Development and innovation,
- The New Product Development process,
- Analysis and communication of a business case for product development,
- Appreciation of business needs and constraints, including cost, manufacturing and other technological and organisational factors, and business strategy,
- Understanding the customer / market for the proposed product,
- Creative methods and professional techniques for NPD ,
- Iterative design cycles that progress the product development effectively,
- Product modelling and presentation using sketching, prototyping, Computer Aided Design (CAD), and visualisation software,
- Client and customer needs assessment and development of a product design specification,
- Creative and systematic development of alternative product concepts,
- Decision making for optimum product concept selection,
- Team based product development and design project management,
- Professional presentation of product proposal.



Figure 1: Course topics and themes listed in the course brochure

Apart from these specific topics, the course includes a number of elements and modules which address the pedagogical considerations mentioned above. Particular emphasis is put on the creation of a learning environment that supports 'learning for understanding' [11]. Therefore, the ENGGEN 405 course contains a range of non-traditional learning activities apart from the usual classroom presentation and discussion elements, such as studio sessions in an art gallery, hands-on workshops on teamwork, learning styles, re-engineering, physical prototyping, and interactions with business managers and site visits. It is based around professional collaboration with a local manufacturing SME as industry partner and client, working on a real-life, commercially relevant product development problem. The project is structured and organised in such a way that it will foster the development and application of creativity, innovation and engineering skills as much as possible. The collaboration with a real-life business provides students with valuable insights, and enables them to acquire a wide set of creative and problem solving skills from this interaction. In particular, it helps students learn to use their knowledge to solve unexpected problems rather than simply recite back facts, and supports learning rich with connection making, i.e. across subject-matter learning, which is necessary for insight and deep thinking [11].

The following sections summarise some of the key course features and aspects which have been designed to achieve these outcomes.

COURSE FEATURES SUPPORTING 'LEARNING FOR UNDERSTANDING'

Project Based Learning Approach

Project Based Learning (PBL) is the core instructional approach of the ENGEN 405 course. Our PBL approach has evolved over a period of more than 15 years in a range of design, industrial engineering and engineering management courses (see e.g. [9]), and is in line with Perkins' learning principles of 'bridging and hugging' [15]. Accordingly, teaching staff, mentors and tutors and external collaborators see it as their main role to help our students connect, extend and apply the knowledge and skills they acquired earlier (either in their academic studies within their discipline or in other contexts) to the solution of their project tasks.

The project is designed and presented in ways which encourage the students to generate, or learn, and apply new knowledge in a meaningful, realistic context. This includes the aspect of 'problem finding' on top of the traditional Engineering mission of 'problem solving'. Another important aspect is learning across subject matters and disciplinary boundaries, for example through the requirement of working as a member of a multi-disciplinary team (see below), in order to achieve a holistic project outcome from a broad range of perspectives.

To achieve all this, the project is structured into four stages of three weeks duration each, starting from a deliberately vague task explanation, as it typically occurs in business practice, followed by three design iteration stages. The project concludes with a 'Reflections on Learning' submission to encourage deep reflection (Figure 2).

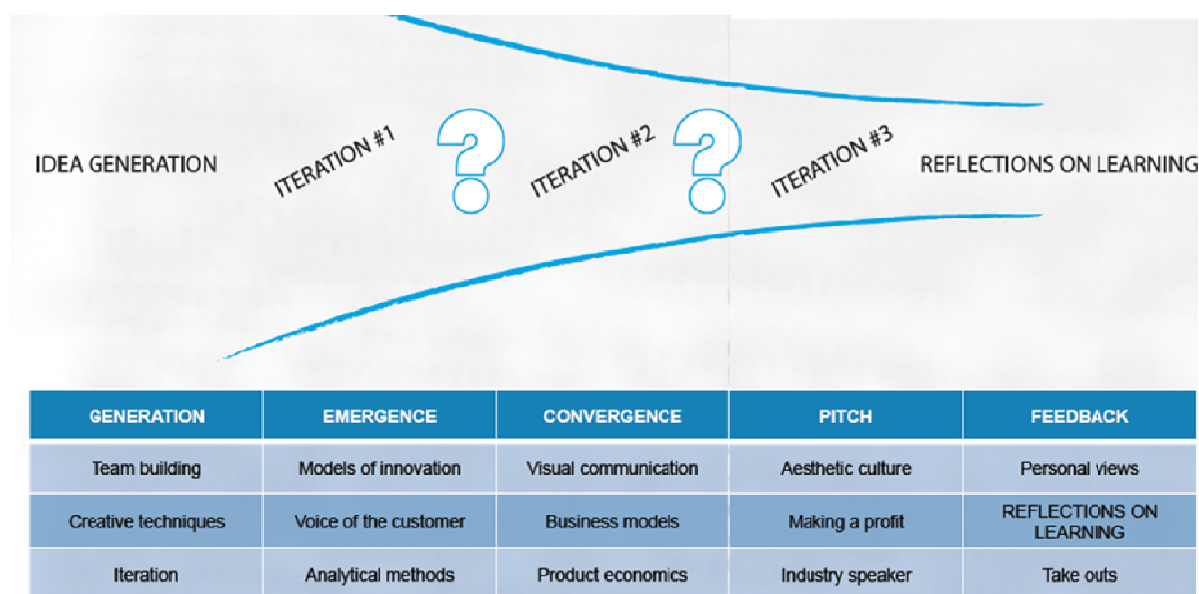


Figure 2: Project phases and themes from course brochure

Idea Generation Phase

In the first course session the students are presented with their initial project task "Develop the concept for an innovative new product for your host company", and are briefly introduced to the current semester's host organisation. This is followed by a site visit and a presentation of one of the host's top managers about their business, where information on

the company's history, current operations and market position from the business perspective is provided. Students are encouraged to raise questions, and are asked to carry out further research to acquire a solid understanding of the scenario and context of their project. In parallel, a range of other supporting course activities takes place, in particular studio sessions to facilitate the students' team building process, to introduce and practice the principle of multi-disciplinarity, and to illustrate the nature of the product development process using hands-on, practical workshop exercises (see below).

Students are informed that at the end of the first three-week project stage, each project team needs to present a 10-minute 'Idea Generation Presentation' in PowerPoint format to the host company and course team. This requirement motivates students to start their learning journey at, or even before, the 'fuzzy front end' of product innovation, by reflecting on potential product development alternatives on the basis of their current understanding of the host's business environment, resources and capabilities, its market position and potential, and its (assumed) strategic direction. Many Engineering students are very uncomfortable with this vague and fuzzy problem finding task, and consider it a significant challenge, as they are accustomed to working on reasonably clearly defined assignments, engineering design briefs, or exam questions in their other curricular activities.

During this difficult stage student teams are supported and mentored by course staff, e.g. during studio sessions, through communication with course staff and host company via the course website, and in a presentation rehearsal session, to help them develop and present one or several new product ideas that in their view fit the host's situation. Representatives of the host company, generally the owner/manager and/or the head of the design department, attend the presentations and provide their comments and critique ad-hoc during the session. Further comments, constructive criticism and decisions on selection of the most promising projects ideas are provided via the course website to each project team after consultation between course staff and industry partner.

Design Iterations and '4 Cs' Principle

Frequent and timely formative feedback, which is coupled with the assessment structure in the course (see below), is also provided in each of the remaining three stages of the project. These stages are dedicated to three cycles of design concept development, which model the converging nature of NPD processes in practice. Each cycle culminates in the presentation of an iterative refinement of the design task that was assigned to each of the student teams. This concept of cyclic, iterative refinement of a design concept, which is a main characteristic of NPD and many other problem solving activities in business practice, is foreign to most students, who during their studies have become accustomed to the traditional, linear approach to solving a task and to learning practised in academic instruction: namely studying a subject, submitting an assignment or sitting an exam on the topic area, getting it assessed, and moving on to the next subject. Therefore, strong emphasis is placed on helping students adjust to this unfamiliar way of problem solving and learning by providing them with ample opportunities for reflection, abundant practice and meaningful feedback.

The concept of the '4 Cs', a cyclic process of 'Comprehend, Create, Critique, and Communicate' developed in the course has proven to be particularly effective in supporting students to develop a more reflective approach to knowledge acquisition and application, and thus fostering their deep thinking. The nature of the 4 Cs is closely related to the four-

step Deming cycle – Plan, Do, Check, Act (PDCA) – of iterative problem-solving commonly used in business process improvement (see e.g. [16]). The 4 Cs are used to structure each of the design iteration cycles, starting from a relatively general and coarse perspective, and zooming in on more specific and detailed design aspects, as students gradually firm up their design solutions.

In the Comprehend phase, students are encouraged to develop and gradually deepen their understanding of the requirements and motivation of their current design step. This covers the acquisition and evaluation of a broad range of issues which have an impact on the design task, e.g. customer (i.e. host company and end user) expectations, technical and organisational requirements and constraints, cost implications, and market conditions.

In the next phase, Create, the students use their understanding to generate solutions to the requirements and issues they encountered in the Comprehend phase. This will generally be in form of conceptual designs and solutions that the team proposes, with increasing levels of depth and detail in subsequent iterative design stages. Students are encouraged to use a variety of approaches to express their ideas, for example written or verbal descriptions, sketches, images, drawings, CAD models, and physical prototypes. A range of workshops in the studio sessions are provided to help them develop their presentation skills, externalise their ideas, and express and communicate their often tacit understanding of the situation.

In the Critique phase students are encouraged to evaluate their proposed concepts, and to identify how these measure up against their stated requirements and constraints. They are also asked to provide a critique of their original understanding, and whether it needs to be modified on the basis of their experience of the concept generation and testing. This is a particularly challenging step for students, who instinctively are rather inclined to defend than criticise their own solutions. However, constructive criticism and open discussion of the merits and demerits of proposed design concepts in a design review meeting is a key factor for successful NPD in business. In the course, we therefore discuss this issue extensively in class, and let the students experience the role of constructive criticism for collaborative development processes through a hands-on ‘micro-NPD’ workshop in one of the first studio sessions.

In the final phase of the 4 Cs cycle, Communicate, students need to submit a clear, short summary of the key elements of the product needing development (or the final product concept in case of the last iteration), and how the preceding Critique phase has shaped this plan of action. The required presentation format has been developed with the input of practising engineering managers and design consultants, and is modelled after a common format used in design reviews in a business environment. The submission is uploaded on the course website and circulated to teaching staff, mentors and design professionals from the host company. They provide their individual feedback and comments on the website and in class sessions within a few days, which are then used by the project teams as inputs into a new cycle of iteration. The final submission after the third iteration includes another formal, oral presentation to all stakeholders involved in the project, including outside professionals and representatives of the host company (usually top management and design staff), as well as interested members of the University community. Each team’s proposal is discussed after their presentation, so students receive concluding feedback on their achievements and on the outcome of their project, including the commercial viability of their concept proposal, from a range of perspectives.

The four-cycle PBL approach summarised above is supported by a range of course activities and features, which help achieve the desired pedagogical aims and course objectives, including deep thinking and reflective learning, the flexible and active use of knowledge, working across disciplinary boundaries, communication skills, and experience with multi-disciplinary teamwork. These features and activities include Studio sessions and a range of hands-on workshops in an art gallery to promote the non-verbal, intangible and kinaesthetic aspects of knowledge in the area of design, engineering and management (Figure 3), an elaborate system to foster and monitor teamwork, and an integrated course assessment programme and communication infrastructure which encourage active learning, and provide meaningful formative feedback in line with our educational targets and practical project aims.



Figure 3: Prototyping workshop

ASSESSMENT STRUCTURE

Meaningful, formative assessment plays a key role in supporting reflective learning and deep thinking [17]. Appropriate assessment is particularly critical in areas such as NPD, where a vast array of information and knowledge from different disciplinary areas needs to be considered, processed and applied. A particular challenge is the assessment of learning which is based on experiential, kinaesthetic, non-verbal and tacit knowledge. Traditional assessment methods are generally based on the examination of factual knowledge and, for example in engineering design, on the evaluation of students' submissions on the basis of a range of tangible, generally predefined, performance criteria.

In our view, a marking scheme based on a set of meaningful, measurable assessment criteria and elements is one of the key tools for motivating students to learn – in particular for those who need strong external drivers such as a course grade to perform to their best ability. However, in our experience this type of assessment, as elaborate as it may be, mainly addresses the tangible and measurable aspects of educational achievement, and

therefore needs to be complemented by additional tools, which concentrate on the more elusive aspects of learning. Another important consideration is the encouragement of reflective and close-loop learning, which depends on timely and high-quality formative feedback and constructive criticism. Critical in a team-based project scenario is also to consider and include assessment features and tools which foster and assess team-based achievements, allow the fair distinction between different levels of individual learning and efforts, and prevent 'free-loading' of individual members in their team environment. An important negative aspect of any assessment scheme that is not based on the comparison of the students' outcomes to specific performance criteria is, that it tends to be much more resource-intensive to apply. In particular it requires a significant amount of time and effort to provide students with constructive feedback that helps them progress beyond their current levels of understanding and achievement.

The assessment system in ENGGEN 405 Advanced Innovation and New Product Development has been developed and continually refined on the basis of these considerations. The overall assessment structure, as published in the Course Outline, is shown in Table 1. It should be noted that while the overall number of assessments shown in the table may appear large, most individual submission elements are relatively small, and the associated workload situation for students and assessment requirements have been carefully designed and are closely monitored to avoid any overload situation.

Table 1: Summarised Assessment Schedule of ENGGEN 405

Assessment Type	Assessment Component	Weighting
Team Assignment	Idea Generation (PowerPoint presentation)	6%
Team Assignment	Concept Development Iteration #1 (PowerPoint presentation)	12%
Team Assignment	Concept Development Iteration #2 (Report)	16%
Team Assignment	Concept Development Iteration #3 (Report and PowerPoint presentation)	22%
Individual Assignments	Weekly Insights from Course Material (Eight one-paragraph blogs)	8%
Individual Assignments	Weekly Workbook (Two short reports in blog format)	8%
Individual Assignments	Studio Work (two short reports in blog format)	6%
Individual Assignment	Reflections on Teamwork (Short report)	6%
Individual Assignments	Reflections on Learning; Professional Involvement and Experience (Two reports)	16%
Total		100%

The assessment components in Table 1 can be roughly categorised into three major groups. The first four components cover the assessment of tangible project progress and outcomes by similar means and mechanisms as used for other engineering design projects, namely project report submissions and oral presentations. The second group, Weekly Insights from Course Material, Weekly Workbook, and Studio Work, are informal, blog-like submissions

which are aimed at encouraging students to actively engage with the course material and activities, and relate them to their project tasks and to the NPD process in general. They require students to actively participate in class activities, and to reflect and report on 'what's going on in class?' and 'how does this relate to our project work?'. The last group, Reflections on Teamwork, Reflections on Learning, and Professional Involvement and Experience, focuses on fostering deeper reflection on all aspects of the course, close-loop learning and the development of deep insights which may go even beyond the topic areas covered in the project.

Project Assessment Approach

The first four components in Table 1 assess the progress and perceived levels of achievement the different project teams have made in each of the four phases of the project, as demonstrated by their online submissions and oral presentations. These marking components mainly assess tangible project achievements and progress made by each of the teams, although other aspects, such as evidence of the application of the 4 Cs approach, are also taken into consideration. Overall they account for 56% of the final course marks. As there is a significant learning curve involved for the students to adjust to the complex project requirements, the weighting increases gradually from 6 marks for the first presentation to 22 marks for the final submission and oral presentation. In order to foster teamwork and team-based development, marks are generally assigned to the team as a whole, but a number of factors and indicators, such as the outcomes of the confidential peer assessment scheme at the end of the course, and the statements made in the Professional Involvement and Experience reports, can be used to moderate the marks of individual students if deemed necessary.

To help students understand the assessment criteria and focus on the important learning aspects of each of the submissions, specific submission guidelines for each are published on the course website and discussed in class. In order to achieve a basic level of uniformity of the submissions, and in particular to keep the students' workload and the assessment and feedback efforts reasonable and manageable, they include suggestions, specifications and size constraints for format and structure of the submission and/or presentation. As pointed out in the previous section, these specifications are also in line with professional practice of design reviews in the industry, where they have been found to be an effective way of facilitating progress in the commercial NPD process. The use of visual tools for illustrating the proposed solution, such as sketches, diagrams, CAD models or short video clips, is strongly encouraged. It is emphasised that the nature of the submission needs to demonstrate the application of the 4 Cs approach introduced earlier. A rough marking scheme is also published, as for example the following breakdown for the Idea Generation presentation (worth 6 marks):

- Quality of insight into the idea - why does it have merit? 50%
- Clarity of story and validity of reasoning 20%
- Presentation technique 10%
- Confidence in the project team to champion the idea through to a concept 10%
- Techniques and/or perspectives used to generate the idea 10%.

Assessment and provision of feedback for the major submissions is shared amongst course staff, mentors and specialists and managers from the host company. Each member of this assessment group is provided with access to the different team submissions through the course website, and required (course staff) or strongly encouraged (external stakeholders) to add their feedback comments, critique and mark suggestions to the submissions on the website. Feedback comments are immediately accessible to the respective project teams once they are entered into the website, but mark suggestions are only visible to the assessment group. These marking suggestions are discussed and can be commented on, and are used as inputs in the final marking process. The final mark allocation is decided by the course director under consideration of all comments and assessments, and then published to the students.

In this way each student team receives a variety of rich feedback and comments from at least two or three different sources and perspectives, which supports the development of deep insights, and a mark which is based on a moderated process and multiple inputs. Each team can only see their own submission and the relating comments and marks, but there is also a section on the website for more general comments and feedback on all submissions. Students are also encouraged to request further clarifications or discussions on any aspects of the feedback and assessment. This is either handled through a discussion thread on the website, but can also be dealt with in studio sessions or in face to face dialogues with course staff (Figure 4).

The screenshot displays a course webpage for 'Idea Presentation'. At the top, the title 'IDEA PRESENTATION' is followed by the names of the course staff: Andrew Kim, Andrew John Colin Wells, David Bjerrum Reeckmann, Maxwell Reinout Uivel, and Alvin Yu. Below this, there are links to various resources: 'Idea Presentation.ppt', 'Idea Presentation Final', and 'Team 6 Idea Generation Video'. A discussion thread is visible with two posts. The first post, by David Bjerrum Reeckmann, asks for feedback on a powerpoint. The second post, by Mehdi Shahbazpour, provides feedback and a link. On the right side, a marking section shows a score of 5 and a comment by David Walker. The comment is positive, praising the professional work and novel ideas while suggesting improvements in maintenance and safety.

Figure 4: Screenshot of course webpage for Idea Presentation with student submission, presentation video, discussion thread and marking section

Activity Blog Submissions

The assessment approach for project submissions described so far appraises mainly tangible learning outcomes, but combined with the structured project approach, the studio sessions, the real-life scenario and the feedback mechanisms and interactions between students, staff and business partners, already provides good incentives and opportunities for deep learning. However, our observations as well as some student feedback from the first

few versions of the course indicated that some of the class activities that we consider especially valuable and important for deep learning, making connections across disciplinary boundaries, and for acquiring tacit, in-tangible and kinaesthetic skills and experience, were not considered as relevant by students as we would have liked. Therefore the 'blog' category of assessments was implemented. The blogs are designed to motivate students to actively participate in class activities, and help them process and externalise new knowledge and information as it is generated.

The Weekly Insights from Course Material are brief, one-paragraph blog entries by each student in the website, which have proven to be very effective in motivating students to attend and mentally participate in class (Figure 5). The blog format has been chosen as many of the 'Web 2.0 generation' of students are familiar and comfortable with this concept, and as it fits well with the other communication and feedback features of the course website. The requirement is simply to reflect on all the formal class activities during the respective week, and identify their relevance to and their potential impact on the project work of the particular student's team. Recommended submission format is a bullet point list or a maximum of one or two short paragraphs. Eight of the 12 potential weekly entries count for up to one mark each. The marking process of these submissions is coarse and fast: zero marks are assigned for no submission, ½ mark for just repeating statements from class, and one full mark for a submission that demonstrates sufficient reflection and transformation of the material.

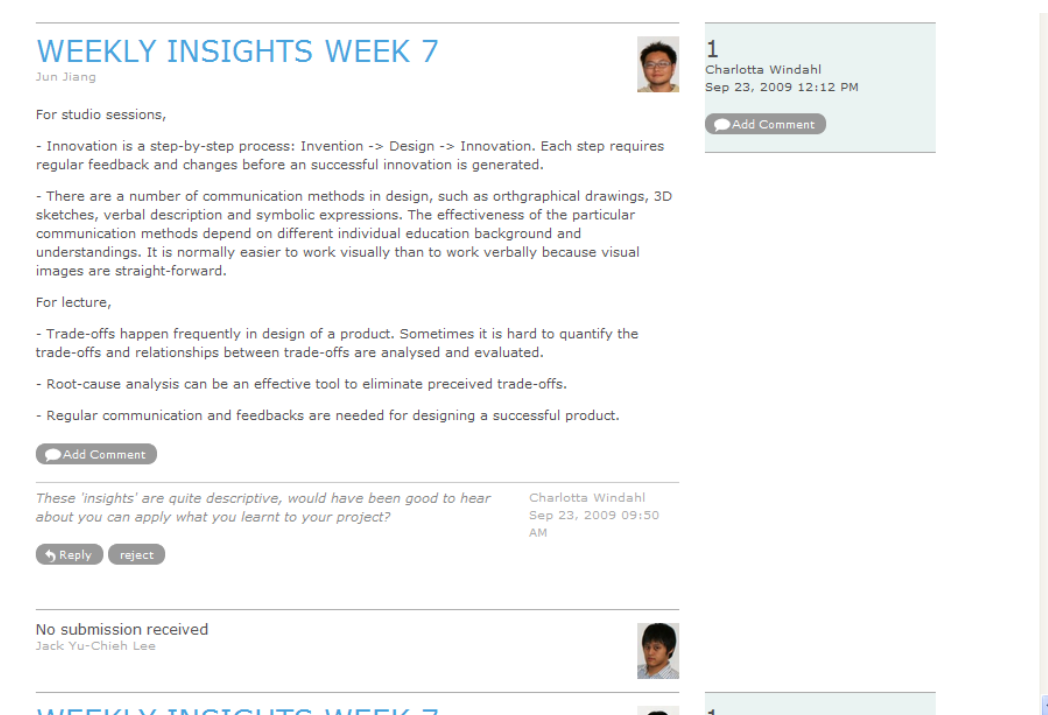


Figure 5: Website screenshot of Weekly Insights

Instead of keeping a formal design workbook for the documentation of their project work, each project team needs to submit a Weekly Workbook, again in the format of an informal blog, to the website each week, alternating between team members. Thus each member needs to submit two workbook blogs at different stages of the project, which count for four marks each. The blogs are expected to summarise the activities of the team in an easily readable and informative manner. Brief explanations of the research, the insights, the

team's ideas and plans, and management of the team are required, and links to useful website resources, images and other visual material should be included. To provide an additional feedback mechanism for the students, students can add specific questions to the assessors relating to the content of the blog. The size of the blogs is typically the equivalent of an A4 page, excluding sketches, diagrams, screen prints of relevant websites, etc. (Figure 6).

Studio Work reports have a similar format, but they cover specific studio sessions with workshops that are deemed of particular relevance to the students' project work. All students submit the reports on the same studio sessions, which are assessed according to similar criteria as the other blog submissions, and count for a maximum of four marks each.

WEEK 3 BLOG
Hsiang-Hung Hsiao

Hi Everyone It has been an exciting week for our team We managed to have several meetings before the Friday presentation and this has worked out pretty well for the design project in terms of idea generation and problem discussions. We will continue to have these meetings for every week if every team ...

[\(more\)](#)

3.75
Rainer Seidel
Aug 26, 2009 11:46 AM
[Add Comment](#)



[\(more\)](#)

[Add Comment](#)

A good blog, but there is still potential for improvement. When you look at the requirements at the top you'll see that the main reason for this blog is to provide us with evidence that makes us confident that your team is on the right track and progressing well. Your explanations and sketches show this to a certain extent, but are they enough 'evidence'? Remember that the blogs replace a more traditional workbook that documents your development process.

Rainer Seidel
Aug 24, 2009 02:06 PM

[Reply](#) [reject](#)

Figure 6: Weekly Blog entry on the website

Reflections on Learning

The final group of assessment components in Table 1, Reflections on Teamwork, Reflections on Learning (RoL), and Professional Involvement and Experience, produce particularly beneficial learning outcomes [18]. These components together account for 28% of the course marks, and require students to consider all issues related to their teamwork, learning process and professional roles. The report requirements encourage students to reflect deeply on their activities and roles during their project development, within their team and in other course activities, and ask them to question their existing behavioural patterns, attitudes, and objectives. Our guidelines for the RoL state the principles and objectives of this submission [19]:

“Personal reflection and internal processing constitute an important part of the learning process. If the reflections are recorded (for example in a blog, a diary, an essay, or a report), this generally brings up additional tacit knowledge and helps consolidate understandings developed during the learning process. The Reflections on Learning task is aimed at achieving these outcomes. Think of your experience in this course – the project work, the

people and team issues, the nature of the NPD process, the studio sessions, the discussions and lectures, etc., etc. – to express what happened with you, what you learned, how you felt, how your viewpoints changed, what insights you developed, and what conclusions you have drawn from all this. Use the ‘iteration’ principle to generate a document that’s more than just a historic review or a casual outpour of feelings. Be profound and critical, but be fair and thoughtful.”

The submitted reports are generally of a very high standard, and reveal deep insights and a high degree of reflective learning during their composition. Apart from their very beneficial impacts on students’ learning, these tools have also provided excellent, in-depth feedback to the course team on all aspects of NPD, learning and organisational issues, which has significantly benefitted the evolution and refinement of our educational approach, and also enhanced the INNOVATIONZ team’s understanding of product development in the broad range of industry scenarios offered by our case companies. Below is a typical comment from a student’s RoL which demonstrates the value of these tools:

“One final and most important insight I had taken away from this course was the ability and need for the reflection process. Prior to this course, it was not common practice for me to reflect upon completed work, therefore reducing the amount of improvements I can have on the next exercise. However in this course, the constant reflections required for lectures, studio sessions and the presentations had helped in identifying the shortcomings and strong points of the work I have done and the key essence from information I had received. It is from these reflections that real “experience” can be gained effectively for the work done, and maximising the amount of knowledge gained from the process.”

TEAMWORK

As mentioned earlier, the ability to function on multi-disciplinary teams has been identified as one of the most important attributes that students are expected to develop during their undergraduate Engineering degree course [7]. Multi-disciplinary teamwork skills are particularly critical in the areas of innovation management and NPD, and therefore have been one of the focal aspects of our course design and activities. In our experience the development of students’ teamwork ability is a complex, challenging and sometimes traumatic process and experience for them, and therefore needs to be carefully organised and monitored. Some of the main factors which need to be considered in this context are team composition and team building, roles and responsibilities within the team, fair distribution of teamwork including the prevention of free-loading, and the resolution of conflicts and disagreements. Another issue which is particularly critical in multi-disciplinary teams and/or in projects which involve the crossing of disciplinary boundaries, is the prevention of the segregation of project tasks into specialist topics within the team. This often happens when some students have existing specialist knowledge or skills, have a strong preference for one particular type of work, or want to avoid specific work areas. Some of these aspects are addressed in the specific PBL and assessment approaches outlined above, and a number of additional tools are used in the course to complement these.

When they enter the workforce, young graduates have generally little or no choice of the team environment and the colleagues they will have to work with. Also, during their degree course, students with like interests and levels of achievement tend to group together, creating their own group culture and norms, shared perspectives of their knowledge and of

their discipline. Therefore we use a number of factors at the start of the course to form project teams (of between four and six students each, depending on class size), which are as multi-disciplinary and as diverse as possible, in order to provide students with a realistic and rich learning environment. Prime factors for team selection are the students' disciplinary background and practical experience, their academic performance, and also their gender, age and ethnicity. Another factor we deem important is the difference in learning styles [20] of the different team members. In order to generate a good mix of learning styles in each project team, we ask students in one of the first workshops in our studio sessions to participate in a test to identify their own learning style, which we then consider in our team composition.

Once the different project teams are established, we run a workshop 'How to start a project team the right way', based on an approach developed at the University of Linköping in Sweden. The topic is briefly introduced in a PowerPoint presentation, then students are provided with a questionnaire and worksheets that help them agree on some general guidelines for how to work together, and to externalise and share each project member's norms and habits in order to avoid conflicts later on. The workshop concludes with the requirement for each team to develop a their own written team contract on the basis of team contract guidelines provided to the class [21]. Further hands-on workshops in our weekly studios are organised to foster team processes and provide students with insights into their roles and behaviours in their team environment, for example a 'Biopics' workshop to support team building (Figure 7), and a 'Broken Squares' workshop to let students experience aspects of cooperation in team problem solving, and to sensitise them with respect to behaviours contributing towards or obstructing the solution of a team problem.



Figure 7: Biopics workshop using visual 'storylines' to help students get to know each other

Another very effective tool to identify and remedy negative factors and habits which affect teamwork is the Reflections on Teamwork assignment (see above), which needs to be between 600 and 800 words long, and be uploaded to the course website just before the mid-term break. Students are asked to reflect on the experiences they have had with teamwork, on the interactions between individual team members and on team dynamics. They must consider their own perspective and expectations and those of other team members, and describe their opinion on teams at the beginning of the course and at the time

of submission. The report is expected to be an open and honest account of each student's thoughts, and should explain the value they have drawn from their experiences involving teamwork which they consider most significant. From our observations and from the feedback in the submitted reports, students find this assignment a very useful way of reminding themselves of sound teamwork habits, and many use their insights to bring their team process back on track. Typical for the insights and conclusions are the following statements from the report of one of the students of our 2010 class:

"... I'm still not fully comfortable about our team's ability in performing at a high level. I feel there is still much more to be done with regards to fully knowing the potential of each member in our team. So far, I have tried to discover the good points in my team to avoid myself feeling discouraged about whether my team is good enough to work together or not. I noticed from my efforts in finding the good points in my team that Kat is good in taking initiative with criticizing (constructively) an idea, and Vikas with initiating team meetings. Sandeep I have noticed is a person who likes to jump into volunteering to finish tasks.

I am hoping that through everyone's efforts in building rapport with each other that there won't be any problems regarding individual preoccupations that might dominate the team's performance. Also, I will continue to look for the good points in each of my team members in this project, and in future projects not just in this course. I know from working previously with other teams that this will help me get through any negative misconceptions that might arise within me when working in a team."

As mentioned above, free-loading has been found to be a major problem in team-based projects, in particular if most team members are interested in achieving an optimum project outcome, and therefore are willing to cover up the poor performance and efforts of a particular team member, rather than 'wasting time' on trying to raise the issue in the team and enforce the rules they imposed on themselves in their team contract. To avoid this problem as much as possible, we use a confidential peer review process, where students must fill in a review form and submit to the website. Students are reminded at the start of the course that this review will be used as an input in moderating the team marks assigned for the major team based assessments.

CONCLUSIONS

The multi-disciplinary nature of the ENGGEN 405 course, and the approach and tools introduced above provide a realistic and very beneficial capstone experience for Engineering students as well as for their peers from other academic disciplines. The emphasis in the course is on the integration of skills in engineering, marketing and design to industrial problem solving, as well as on the development of our students' ability to generate and apply new knowledge in a meaningful, boundary-spanning context.

Feedback from industry partners and students of the programme has been very positive and appreciative of the real-life problem-solving and learning [22]. The value and effectiveness of the approach are best demonstrated through some of the statements of our students in their Reflections on Learning:

"... In conclusion, I am delighted to have completed the course. My initial expectations of the course being different to anything else I had ever done before at university has been surpassed profoundly and as a result I feel it being nothing more than an accomplishment to

be able to say that, yes, I have done it. Yes, it was in some ways the hardest and most difficult paper in terms of its open-endedness I have ever had to do and yes, I have made it to the other side with a new set of skills that some would say are unique for a student to have. The course has strengthened my teamwork skills as well as my project management skills and I would do nothing more than to encourage my peers to do the course.”

“... During this course I learned more than just the iteration process for developing new products but also about project management and team dynamics amongst other things. I think the most important thing I have taken away from this course is the real process of iteration. Not just the how-to guide or a list of steps, but actually experiencing it, seeing how different it is from the other side and how much is gained by cycling through it.”

“... I’ve learnt more from the assessments and my team members than I ever could have from reading a textbook on the subject of NPD. I’m glad that I took this course in my last semester at university because it helped me integrate all the skills I’ve acquired from all my majors in the past 4 years and better prepared me for the working world.”

“... I am sure that as I move forward I will be in situations where I step back to think a moment and realise, that the reason I took the certain actions I did was because of the skills learned throughout this semester. For me this is exciting, I am not memorising information for an exam and then forgetting about it once it is over. I have developed skills through practical application that will continue to help me contribute to everything I do.”

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DEVELOPING ENGINEERING DESIGN CORE COMPETENCES THROUGH ANALYSIS OF INDUSTRIAL PRODUCTS

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ABSTRACT

Most product development work carried out in industrial practice is characterised by being incremental, i.e. the industrial company has had a product in production and on the market for some time, and now time has come to design a new and upgraded variant. This type of redesign project requires that the engineering designers have core design competences to carry through an analysis of the existing product encompassing both a user-oriented side and a technical side, as well as to synthesise solution proposals for the new and upgraded product. The authors of this paper see an educational challenge in staging a course module, in which students develop knowledge, understanding and skills, which will prepare them for being able to participate in and contribute to redesign projects in industrial practice. In the course module Product Analysis and Redesign that has run for 8 years we have developed and refined a product analysis method and a staging of it, which seems to be very productive. Product Analysis and Redesign is a first year course module of the bachelor education Design & Innovation at the Technical University of Denmark. In this paper we will present our product analysis method and we will reflect on the empirical material from the students' application of the method as a means to verify it. We will discuss the product analysis method and the course module in relation to the CDIO-approach, and we conclude that the product analysis method is an important contribution to the conceive stage, is relevant for many engineering disciplines, and can be applied in engineering education from first year.

KEYWORDS

Product analysis method, redesign, industrial products, conceive, competences.

1 INTRODUCTION

Many product development projects in industrial practice are directed towards designing a new and upgraded variant of an existing product, which has been on the market for some time. These redesign projects require that the engineering designers understand needs and requirements from users and other stakeholders, and know how the existing product functions and how it is manufactured. Thus, for an engineering designer to be able to

contribute to a redesign project, he/she must have competences to carry through a composite analysis of the existing product and how it is used and valued by the users. The analysis has to encompass both a user-oriented and a technical perspective, and the analysis result has to provide the engineering designers with an understanding of the product's *raison d'être* as well as attractive and realistic improvement potentials.

Our educational challenge is to stage a course module, in which the students build competences to participate in and contribute to redesign projects. In the course module Product Analysis and Redesign that has run for 8 years we have developed and refined a product analysis method and a staging of it, which seems to be very productive in building the students' competences.

Since the course module Product Analysis and Redesign was developed in year 2002 it predates the CDIO-approach [1]. However, with respect to 'conceive' we see some similar formulations. Crawley et al. [1, p. 8] define, "*The Conceive stage includes defining customer needs; considering technology, enterprise strategy, and regulations; and developing conceptual, technical, and business plans.*", which overlaps with our formulation from the previous page: "These redesign projects require that the engineering designers understand needs and requirements from users and other stakeholders, and know how the existing product functions and how it is manufactured." Unfortunately, in [1] only a few lines are given to unfold the definition of conceive, and among the CDIO standards [1, p. 35] we do not find a standard regarding conceive. We believe that the course module Product Analysis and Redesign contains interesting and relevant elements with respect to 'conceive', and we hope the CDIO community will find inspiration towards formulating a Conceive standard and/or a set of guidelines.

In this paper we will present our product analysis method and its staging within the course module Product Analysis and Redesign. The product analysis method has been applied for 8 years on 45 industrial products and close to 500 students and we will use empirical material in order to verify the method.

The structure of the paper is the following: In the next section we will briefly describe the course module Product Analysis and Redesign in order to outline the educational context of the product analysis method. In section 3 we will present our product analysis method and its staging within the course module. Then in section 4 we will reflect on the empirical material from the students' application of the method as a means to verify the method. In section 5 we will discuss the product analysis method and the course module in relation to the CDIO-approach and we conclude.

2 THE COURSE MODULE PRODUCT ANALYSIS AND REDESIGN

In this section we will briefly describe the course module Product Analysis and Redesign since it constitutes the educational context of the product analysis method. Product Analysis and Redesign is a first year course module of the bachelor education Design & Innovation at the Technical University of Denmark. The purpose of the course module is to build the students' competences, so a student will be able to participate in and contribute to redesign projects in industrial practice in his/her professional career.

Let us imagine a product development project in an industrial company where the project goal is to design a new and upgraded variant of an existing product, which have been at the market for some time. The company has set up a suitable design team with respect to size and disciplines to carry through the project. For a successful redesign project it is required that the team members not only can synthesise a new and different technical solution. It is paramount that the design team members understand needs and expectations from users and other stakeholders, in order to increase the probability that the new and different solution

results in a product, which will be seen as attractive and upgraded by users and potential customers. Thus, for the engineers to be able to contribute to the redesign project they have to have the following four engineering design core competences:

1. A *mindset* so they can identify values seen in the users' perspective.
2. To be able *to conduct research* where they analyse an existing product and explore how users use and perceive the product in order to identify improvement potentials.
3. To be able *to synthesise* solution proposals using creative and systematic methods.
4. To be able *to document* the research and the synthesis results.

We have developed the course module Product Analysis and Redesign based on our understanding of redesign projects in industrial practice as it is described in the previous paragraph. The three central ideas in the course module design are:

1. The course module shall develop the students' knowledge, understanding, and skills toward the four engineering design core competences.
2. The learning activities, learning objectives, and assessment methods have to be aligned, [2].
3. Each student design team shall have an existing industrial product to analyse and redesign.

To the authors' knowledge there does not exist a textbook on redesign. We are aware of a textbook in reverse engineering [3], but this book has a too narrow technical focus for our purpose. However, with respect to teaching synthesis (core competence no. 3) there exist several textbooks on engineering and product design, [4], [5], [6], and [7]. We have chosen to use Cross' textbook [4] in the course module for two reasons: Cross' description of the design process is in line with our understanding, and the amount and undergraduate level of text is suitable. For the course module to fulfil its purpose we have to supplement Cross' textbook with a product analysis method and with a way to document the research and synthesis. The product analysis method shall make the students able to analyse an existing product with respect to function and manufacture and to explore how users use and perceive the product in order to identify improvement potentials in the users' perspective. The method is described in the next section.

As a means to document the research and synthesis we teach the worksheet technique. The worksheet technique has been used in the teaching in engineering design at our university for at least 30 years. We do not know an original reference to this technique, but Hansen [8, p. 57] describes the worksheet technique: "*A work sheet is written in a fixed layout with a heading containing topic, name and date. A work sheet forms an information entity, which clarifies a certain topic or aspect, e.g. requirements, setting up solution alternatives, consideration with respect to life phase, or evaluation and decision. A work sheet may be from one page up to 20 pages. Several techniques are used in the work sheet, e.g. writing notes, sketching and drawing, diagrams from experiments, and photos. ... Thus, work sheets contain the designer's considerations and arguments during design work.*" Figure 1 shows a page from a work sheet on the design of a landing gear of an ultra light air plane.

The course content consists of Cross' textbook on product design, the product analysis method to understand both the user-oriented and the technical side of a product, and the worksheet technique to make simultaneous documentation of the student design team's considerations, clarifications, arguments, and decisions. The course content is applied on an existing industrial product, which a student design team has to analyse and redesign. Aligned with these learning activities we have defines the following set of learning objectives of the course module [10]:

Nr: 11-1	Kapitel: Understel
Side 2	Bilag: Understel; valg af struktur
af 5	

28/11

Ved 3 hjul har man en god sikkerhed for at alle hjul er i kontakt med underlaget næsten uanset dets belæfthed. Dette kan man ikke være sikker på ved understel med flere hjul, hvis underlaget er ujævnt. Den ekstra vægt fra det ekstra hjul og ben og dets styring ræffærdiggør flisyvelens ide. den ekstra sikkerhed med vægning o.lyn. Ved oprækkeligt understel giver det ekstra hjul og ben problemer med plads.

① bruges implicit med de andre i højere eller lavere grad. Uden yderligere fordybelse i denne problematik vil vi vælge ② da denne er langt lettere at producere, servicere og vejer mindre end ① og ③.

Næsehjulet anbringes på kroppen af symmetrienssyn og de styringer til næsehjulet kan laves simpelt. Hovedhjulene kan fastgøres til krop eller vinge.

	① EDDP	② VINGE	③ TIPPER
Fordele	<ul style="list-style-type: none"> * Kan bruges uanset vingeplacering * Ge' flertal alu' til oprækkeligt understel 	<ul style="list-style-type: none"> * Kan bruges uanset vingeplacering * Flyet er uanset hjulplacering og adskillelse for transport. Hvis dulleflade er indfor forstyrtningens område er understellet 	<ul style="list-style-type: none"> * Kan bruges med lavt/lidt vingede fly
Ulemper		<ul style="list-style-type: none"> * Store problemer med styringsmekanik landing (fly med denne type er ofte andet til ① eller ②) 	

Alternativ Forløst!

Figure 1. A page from a work sheet. Four alternative ideas for a landing gear of an ultra light air plane are considered, [9]

“A student who has met the objectives will be able to:

- describe a product's structure, mode of action and embodiment (mode of action analysis).
- describe a product's manufacturing and assembly (manufacturing analysis).
- identify the socio-technical context, which the product is part of, and clarify the assignment of meaning in use through interview with and observation of different actors (user analysis).
- interpret the results from the three analyses into a number of improvement aspects and on this basis formulate requirements and criteria for a specific redesign task.
- create solutions alternatives for a specific new embodiment using a combination of systematic and creative techniques.
- select and detail solutions considering functionality, manufacturing and use.
- make a technical assessment of the merit of the solution alternatives with respect to requirements and criteria.
- argue for value in use based on the change in the socio-technical context.
- make work sheets to document observations, considerations, solutions, experiments and decisions in the work with analysis and synthesis.
- read and discuss the work sheets made by others as a mean to share collected knowledge in the analytical work and clarifications during synthesis work.
- redesign a product based on the relevant analyses and the proposed alternative solutions.
- reflect on the quality of the redesign activity and own contribution.”

The relations between learning objectives, learning activities, and engineering design core competences are intended to be the following. Learning objectives A, B, and C constitute the requirements of the product analysis method on the one side, and contribute to building core competence 2: To be able to conduct research on the other. Learning objectives C, D, and H contribute to building core competence 1: A mindset to identify values in the users' perspective. The learning objectives E, F, G, and K are aligned with Cross' textbook on the

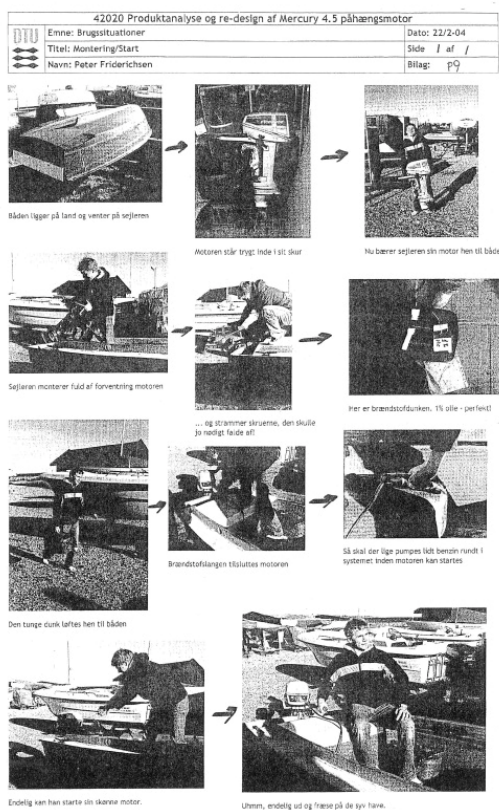
one side and contribute to building core competence 3: To be able *to synthesise* on the other. Learning objectives I and J are aligned with the worksheet technique on the one side and contribute to core competence 4: To be able *to document* on the other. The last learning objective L regarding the student's reflection on the redesign activity and his/her own contribution is intended to make the student aware of his/her personal development of knowledge, understanding, and skills by participating in the course module.

3 THE PRODUCT ANALYSIS METHOD

In this section we will describe our product analysis method. Firstly, we describe the theoretical basis of the model, and thereafter three important elements in the staging of the method in the course module Product Analysis and Redesign.

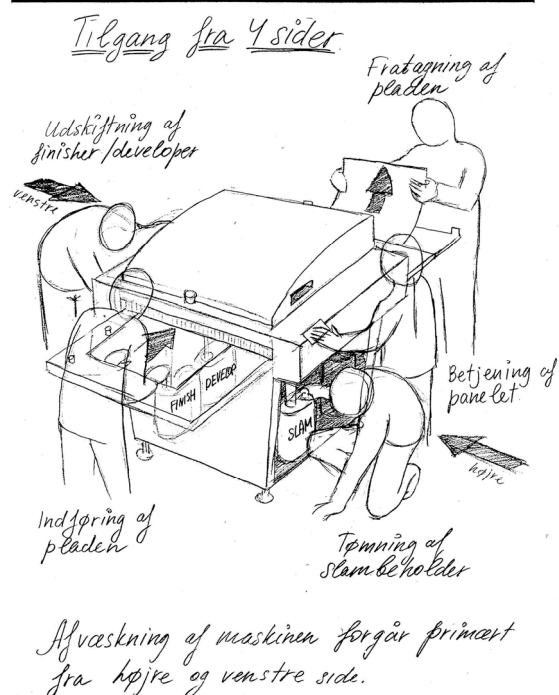
The product analysis method

The educational goal with the product analysis method is to give the students an understanding of both a user-oriented and a technical side of a product. The user-oriented side is related to how users use and perceive the product, and the technical side is related to how the product functions and how it is manufactured. Thus, the students have to develop a mindset that a product is not a technical artefact having value in itself. Value is to be found in the users' reaction when they use the product, i.e. value of the product has to be seen in the user perspective.



(a)

GLUNZ & JENSEN Produktanalyse og Redesign af Raptor Silver 85			
Emne: <i>Produktets proces</i>	Bilag: 6		
Afsnit: <i>Analyse</i>	Side: 1/1		
Note: <i>Tilgang fra 4 sider</i>	Dato: 30.03.2004		
Kursus: 42020 Produktanalyse og re-design	Id: DM		



(b)

Figure 2. Two work sheets on use processes. (a): Shows the operations involved in mounting an outboard motor on a boat, [15]. (b): Shows that the developer for large printing films has to be accessed from all 4 sides, [16].

The fundamental idea in our product analysis is based on the domain theory [11], [12], which states that a product to be designed can be seen by the engineering designer in three

domains. Firstly, the *activity domain* where the engineering designer focuses on the purposeful transformation when using the product, e.g. when a person uses a tumble dryer to dry clothes, the clothes are transformed from being wet to being dry. Secondly, the *organ domain* where the engineering designer focuses on the product's active elements (the organs) which create physical effects, and their mode of action. In a tumble dryer we find e.g. a revolving drum, a burner, and a blower. The revolving drum is an organ which makes the clothes tumble, and the burner and blower are organs, which create a flow of hot air to make the water evaporate from the wet clothes. Thirdly, the *part domain* where the engineering designer focuses on the allocation of the organs into parts, which can be produced and assembled.

In accordance with the domain theory and the goal to understand both the user-oriented and the technical side of a product we have developed a *product analysis method*, which encompasses three analysis dimensions:

1. *Use process analysis*: To understand users and other relevant stakeholders, e.g. maintenance, repairing and disposal.
2. *Mode of action analysis*: To identify the product's organs and their mode of action.
3. *Manufacturing analysis*: To analyse the production of single components (parts) and their assembly into a complete product.


The *use process analysis* is based on a socio-technical approach [13], [14]. The student design team has to identify a relevant actor-network related to the existing product and collect information from the actors. Actors can be human, e.g. users and maintenance persons, and information collection can be carried out by observing actors in action or interviews. Actors can be non-human, e.g. legislative requirements with respect to the product and its use, maintenance, or disposal, and the information collection is carried out by discourse analysis of documents. Figure 2 shows two work sheets on use processes.


The *mode of action analysis* is carried out in the workshop. The student design team takes the product apart (product dissection), identify the organs and their mode of action. Let us imagine a student design team taking a tumble dryer apart. The team has identified an electrical heater as an organ to heat air, and a blower as an organ to create a flow of air. However, the team realises that the heated air flow has to be directed through the revolving drum, and they identify the airway as an organ. The airway consists of sheet metal plates to direct the air flow and holes in the revolving drum to lead the air through the tumbling clothes. Figure 3 shows two work sheets regarding mode of action of a Christiania bike.

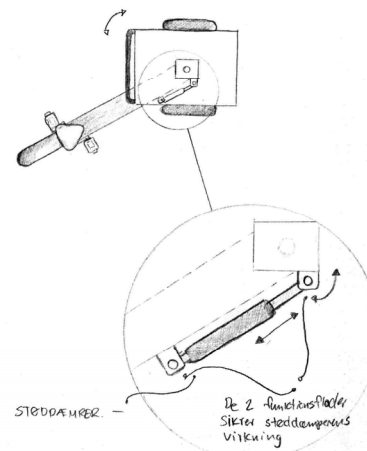
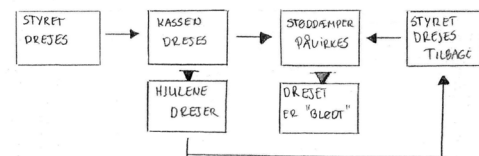
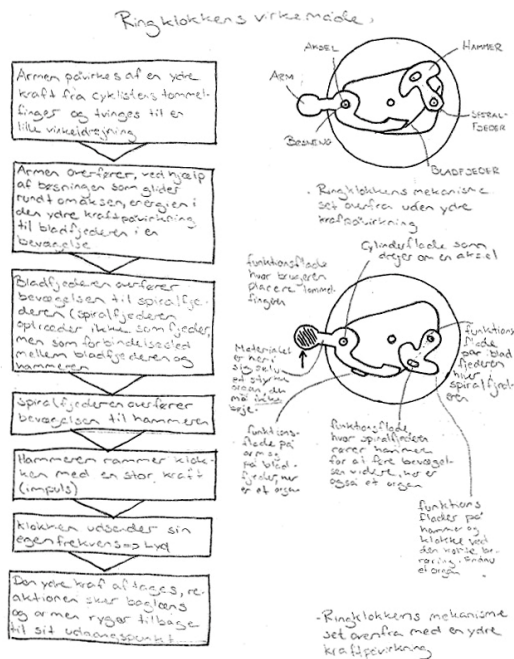
The *manufacturing analysis* is carried out in the workshop. While the student design team disassembles the product they identify single components and reason about the assembly sequence. For each component the type of material and manufacturing process is to be identified. An important element is the identification of *signs* given by the component, e.g. feeling the weight and temperature when holding the component in the hand to identify the type of material, and looking for signs from the production process, e.g. cutting marks from a milling machine or angles from a sheet metal bending. Figure 4 shows two work sheets of manufacturing analysis of a concrete mixer.

For each of the three analysis dimensions we have formulated some inspiration questions to initiate the product analysis. The questions are generic in the sense they are relevant to many industrial products. As a student design team works on the product analysis related to their given product and begin to provide answers to the inspiration questions, new specific questions emerge to be answered. Thus, gradually the students' insight and understanding of the user-oriented as well as the technical side of the product grows. Our product analysis method is not characterised by carrying through a given sequence of method steps, which leads to a required result. The method is characterised by a spiral movement through the three analyses, use process-, mode of action-, and manufacturing analysis. In this spiral

movement the student design team builds an understanding of “what is good?” and “what could be better?” in the users’ perspectives as well as insight into the product’s mode of action and how it is manufactured. We apply two stopping criteria for the product analysis. The analysis has to be carried through within a given time period, and the analysis has to result in the student design team’s formulation of three improvement potentials.

DTU	42020 - Hold 1 Christiania-bike		
Navn:	ICH	Dato:	05-04-2005
Emne:	Ringklokke	Bilag nr.:	1
Note:	Virkemåde	Side:	1 / 2

DTU	42020 - Hold 1 Christiania-bike		
Navn:	BMH	Dato:	05-04-2005
Emne:	Dæmper	Bilag nr.:	3
Note:	Virkemåde	Side:	1 / 1



(a)

(b)

Figure 3. Two work sheets regarding mode of action of a Christiania bike. (a): Shows the mode of action of the of the bell using 2 drawings and a flow chart. (b): Shows the damping mechanism to obtain smooth turn, [17].

The staging of the product analysis

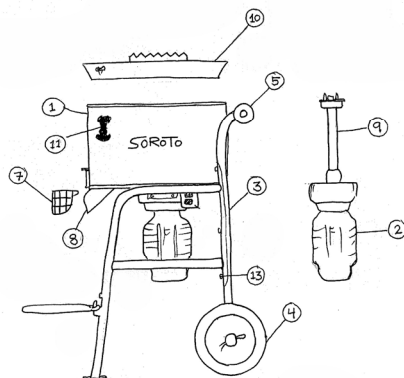
There are three important elements in the staging of the product analysis method in the course module Product Analysis and Redesign. Firstly, we use existing industrial products, which the student design teams have to redesign. To each student design team is assigned *a product and a company contact person*. The company contact person is available to answer questions and to help the team to identify and make contact to users and other relevant stakeholders, e.g. maintenance persons. This is beneficial especially in the initial stage of the product analysis, but the company contact persons also has a positive effect on the students’ motivation, because he/she is looking forward to see the student design team’s solution proposals for an improved product

Secondly, in order to make an extensive and detailed product analysis within the time frame given we let the students work in rather large design teams. Each student design team has 10 members. With careful supervision regarding task delegation and knowledge sharing a 10 person’s student design team is able to carry through an extensive and detailed product analysis. Whereas a large student design team is suitable for the product analysis, this is not good for the redesign task. Since the students are first year undergraduates, their technical discipline knowledge is modest, which means the redesign task must not be complex. And it is overkill to ask a 10 person’s student design team to carry through a noncomplex redesign

task. We solve the problem in the following way. The large student design team has to carry through their product analysis and identify and formulate at least three improvement potentials, and thereby establish the basis for at least three redesign tasks. Thereafter, the students distribute themselves into two 5 person's student redesign teams, and each redesign team selects an improvement potential to pursue. We obtain redesign teams of a suitable size, and the company contact person receives solution proposals for an improved product with respect to two different improvement potentials.

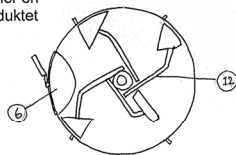
Fremstilling og montage

Neden for ses rækkefølgen, som arbejdsbladene er ordnet i. Nummereringen på denne side henviser kun til denne illustration



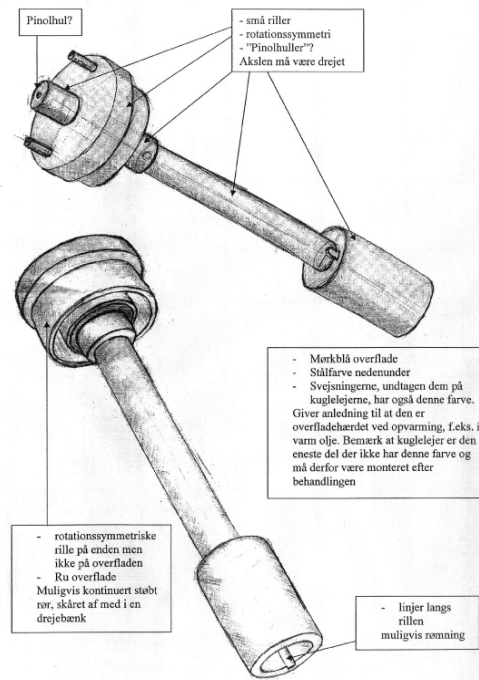
Det første arbejdsark omhandler en systematisk adskillelse af produktet

- 1 Blandekar
- 2 Motor/gearkasse
- 3 Stel
- 4 - 5 Hjul
- 6 - 8 Udløb
- 9 Udgangsaksel
- 10 Låg
- 11 Gummiås
- 12 Blandearme
- 13 Bolte og møtriker



(a)

42020 – Produktanalyse og Redesign		Bilag nr.
Cementblender, Soroto, DTU Design Ing – Gruppe 4		F 7
Dato:	Titel/Emne: Udgangsaksel – fremstilling	Side nr.
26/ 03/2006	ID: TVG	1 / 2



(b)

Figure 4. Two work sheets of manufacturing analysis of a concrete mixer. (a): Shows the concrete mixer's components. (b): Shows the analysis of the shaft's materials and manufacturing using signs like machining marks, colour and weight, [18].

Thirdly, a general idea in the Design & Innovation education is that the students must be able to communicate graphically during design. Both when they are working individually, and in meetings, workshops, brainstorming, etc. We therefore require that they train their hand drawing skills, and for the same reason we postpone the training in computer drawing until the second year. Hand drawing furthermore has the advantage – especially compared to photo – that only the relevant details are presented. The work sheet in figure 4 (b) is a good example of this. The overview of the concrete mixer is much clearer in this type of drawing that only display the product components in focus. A photo would show a lot of other unnecessary information that would blur the communication. However, photos are often beneficial when documenting a sequence of user operations. The work sheet in figure 2 (a) is an example of this. The photos give a very realistic understanding of the user's perspective when mounting the outboard motor.

We see this section contributing with two elements towards formulating the content of Conceive guidelines. Firstly, a product analysis method which has a theoretical basis and encompasses three dimensions: a use process analysis, a mode of action analysis and a manufacturing analysis. Secondly, a mindset element to identify values seen in the users'

perspective, where the key point is that “what is good?” and “what can be better?” are not determined or decided by the student design team.

With reference to the condensed CDIO syllabus [1, p. 55] the product analysis method and its staging proposes some means for a teacher to consider. To develop the students’ ‘professional skills and attitudes’ (syllabus element 2.5) the product analysis method and its staging offers both a rather large student design team and access to company contact person and users. With respect to syllabus element 3.2 ‘Communication’ work sheets with writing, sketching, various types of drawings and photos is an important technique.

4 RESULTS: VERIFICATION OF THE PRODUCT ANALYSIS METHOD

In this section we will collect evidence to verify the product analysis method. Firstly, we describe our empirical material and thereafter we will reflect on the material focusing on the following questions:

- Lessons learned by the teachers: what went well and where is room for improvement?
- Has the mindset element been understood?
- Have all three elements in the analysis, viz. use process, mode of action and manufacturing been considered properly?
- Does the final redesigned product represent significant improvements which are valued by the industrial client?
- Do the students use the methodology later on in their study?

Finding products is a returning pleasure and challenge, since we every year has to find 6 new products and preferably also industrial partners. The procedure is that we brainstorm on possible new products. Industrial partners are then contacted. There are 4 basic criteria that the products have to meet:

1. There should be a plurality of relevant human actors, e.g. users, maintenance personnel, and cleaning people.
2. The products must have a manageable technical complexity that can be handled in the mode of action analysis.
3. Reversible disassembly should be possible and the products must represent a reasonable amount of different materials and manufacturing processes. It is an advantage if there is a production facility for the students to visit.
4. The products have to be of a reasonable size, so they can be handled in the workshop.

In the years 2003 until 2010 we have worked with a total of 45 products. There were 20 consumer products and 25 professional products. Thus, 45 student design teams carried through a product analysis, and then split up into the smaller student redesign teams. In total 92 student redesign teams have redesigned the products.

In order to illustrate the range of products we have used in the course module, we have selected 9 products as shown in figure 5. There are 4 consumer and 5 professional products:

1. The Christiania bike is a carrier bicycle that primarily is used by families with small children as an alternative to a car in urban areas. The bicycle is also used professionally e.g. for mail delivery, but the professional users constitute a very small market segment compared to the consumer market.
2. The food mixer is primarily used for mixing bread dough and is targeted towards the upper end of the consumer market and the lower end of the professional market.
3. The electrical stove is an ordinary household kitchen element with 4 cooking plates and an oven.
4. The train seat and table are used in the Danish intercity trains. As the students are regularly train passengers they know the use of seat and table very well. Therefore we classify the train seat and table as a consumer product.

5. The oil sampling box kit is used by the inspection authorities to take samples of oil spills at sea in order to collect legal evidence.
6. The unit for parcel handling is used when loading and unloading parcels in freight air planes.
7. The tilting kettle is a large pot for preparing food in professional kitchens like cooking potatoes or making stews.
8. The developer is used for processing large printing films used in the printing industry.
9. The concrete mixer is used by masons for preparing the mortar or the light concrete.



Figure 5. Examples of products used in the course module. The first four are consumer products and the rest are professional products: 1: Christiania bicycle, 2: Food mixer, 3: Stove, 4: Train seat and table, 5: Oil sampling box kit, 6: Parcel handling in aircrafts, 7: Tilting kettle, 8: Developer for large printing films, and 9: Concrete mixer.

Lessons learned by the teachers

Being three persons in the teaching group it has been natural regularly to reflect on the progress within the course module. This is done both informally and more formally when we meet for the brainstorm and after each of the course module milestones.

A first lesson learned is the apparent difference between the way students handle professional and consumer products. We have experienced that in general professional products are better suited than consumer products in the product analysis. The statistics in table 1 qualifies our experience. We have classified the 45 products that have been analyzed and redesigned so far in the course module as either professional or consumer products, depending on whether the products are targeted towards professional users or the customer market. There were 42 student redesign teams working with consumer products and 50 student redesign teams having professional products. When calculating the average of grades of all students there is a difference of about one grade between students working with the two types of products. For students working with consumer products the average grade is 7.9 while students working with professional products got 8.9, see table 1. This is a remarkable difference and confirms our experience. However, we do not conclude that consumer products should not be used in this type of course module. Instead our message is that one should be aware of the problem and accordingly instruct the students to avoid it.

Table 1.
Average grades for student teams working with consumer or professional products. The grading scale goes from -3 to 12, where -3 and 0 are failing, 2 is just passed, and 12 is excellent.

	Number of student design team (10 person's groups)	Number of student redesign teams (5 person's groups)	Average grade
Consumer products	20	42	7.9
Professional products	25	50	8.9

A second lesson learned concerns the number of persons in the student design teams. In the first year we only had 4 products which with 60 students gave 15 persons in each student design team. We believed that the large team size would force the students to organize themselves better. However, the experience was that this was not fruitful, e.g. at one occasion the members in one student design team could not agree, which resulted in a conflict. Thus, we decided a student design team size of 10 persons during the product analysis.

A third lesson learned concerns "product fixation", i.e. seeing and understanding not only mode of action and manufacturing but also users and use process from the product's perspective. The first time the course module was run we experienced some student design teams developing a product fixation. We identified the cause of this unfavourable product fixation in the fact that these student design teams initiated their product analysis in the workshop taking the product apart. In year 2004 we introduced a rule saying it is not allowed to take the product apart in the first three weeks of the product analysis. This rule forces the student design teams to work outside-in, and since the introduction of the rule we have not experienced whole student design teams developing product fixation.

Understanding the mindset

A central objective in the course module is to make sure that the students develop the mindset that a product is not a technical artefact having value in itself, but that value is found in the users' reaction when they use the product. To evaluate if this objective has been met we can look at the proposed improvement potentials and the underlying argumentation which is the outcome of the analysis. We have looked at the 9 products shown in figure 5. The 9 products were selected as examples of both consumer and professional products. Table 2 describes the improvement potentials for the 9 products proposed by the student design

teams, and our comments on their relevance. We determine the relevance of a proposed improvement potential by judging whether a product which is successfully redesigned with respect to the proposed improvement potential will be valued as better in the users' perspective. The table illustrates our assumption that it can be problematic to use consumer products for teaching product analysis and redesign since students know the products in advance and are therefore less eager in consulting a range of relevant users. They think that they already know many of the answers themselves from their own daily practices.

Table 2
Improvement areas for the 9 products shown in figure 5 and comment on relevance

	Type of product	No. of improvement areas proposed by the student design teams	Teachers' comments on relevance
1. Christiania bike	Consumer	3 areas: Theft protection, performance, accessories	Two very relevant areas
2. Food mixer	Consumer	3 areas: Additional functions, interface/ security and appearance/ mobility	The areas have only limited relevance
3. Stove	Consumer	3 areas: Cleaning, appearance and efficiency	The areas have only limited relevance
4. Train seat and table	Consumer	7 areas: Cleaning, adjustment, comfort (3 types), luggage, newspapers	The areas are relevant but unclearly described
5. Oil sampling box kit	Professional	6 areas: Usability (transparency, sealing, overview), content (oil container, sampler, extra elements)	All areas are very relevant
6. Parcel handling in aircrafts	Professional	4 areas: Ergonomics, maintenance, efficiency, inviting use	Two of the areas are very relevant
7. Tilting kettle	Professional	2 areas: The cooking process (8 topics) and cleaning (5 topics)	The two areas are very relevant
8. Developer for printing films	Professional	6 areas: Access, cleaning, four problematic components, automation, ease of use, change of context	Three areas are relevant
9. Concrete mixer	Professional	4 areas: Transport, safety, cleaning and appearance	Three areas are very relevant

The students proposed a varying number of improvement potentials for the 9 products ranging from 2 to 7. The analysis of the professional products more often resulted in good and relevant improvement potentials, which are in good agreement with our assumption that the students make a better use process analysis for products of which they have no personal experience with.

An example of how a good use process analysis resulted in very relevant improvement potentials is the film developer (no. 8 in figure 5). It was easy to recognize poorly functioning technical details like a lid that is difficult to close. But a significant improvement potential was uncovered when the working and cleaning procedures was studied in collaboration with operators. Here the students noticed that it was necessary to have access to all 4 sides of the machine, and the workers therefore had to move around the machine in order to perform the different activities, see figure 2 (b). This made the operation of the machine less efficient and limited the placement of the machine to positions away from the wall. A relevant improvement potential was therefore to investigate if the machine could be redesigned so it could be operated from one or two sides only.

Another example illustrates how a poor use process analysis leads to improvement potentials with limited relevance. All the students were familiar with food mixers from their own kitchens, and their own private opinions heavily influenced which problems they identified. The existing food mixer (no. 2 in figure 5) was quite large and targeted consumers that were willing to buy the relatively expensive mixer. The student design team proposed to reduce the size and appearance (give it a more fancy look), but they could not document that the user group (which is very different from students who have limited budgets and space in their homes) would value such improvements. The product reminded too much of artefacts from the students everyday life and they could not abstract from their own opinions, which in this case highly biased the use process analysis. The student design team working with the stove (no. 3 in figure 5) had similar problems, since all students were using one at home, and therefore were reluctant to find representative users.

The three analyses

Another objective in the course module is to ensure that the students build knowledge, understanding and skills within all three product analysis dimensions, viz. use process-, mode of action-, and manufacturing analysis. All student design teams conduct the three analyses, but the quality naturally varies. In the previous section we discussed one of the pitfalls for the use process analyses. We will here look at the two other analyses.

Our approach is to let the product motivate and direct which detailed analyses that the students will carry out. The mode of action analysis can be approached in a number of ways. A traditional one would be to describe the functions and sub-functions in the product and what means that are used to make this happen using a function-means tree. We use the 'organ' notion to document the means as described earlier in the paper. To investigate the dynamics of a product we have good success in using a technique that can be called 'a medium's passage through the product'. This can be illustrated by the concrete mixer (no. 9 in figure 5) where we can look on how electricity passes through the product. From the power outlet the electricity passes through a cable to a power-switch, further on to a safety switch that detect if the lid is closed and then into the electric motor where a rotary motion is generated. This is an intuitively easy technique to use and gives good insight into especially more complex products.

The manufacturing analysis is supported within the course by theoretical lectures where the different manufacturing processes are explained and students try to operate some of them in the workshop. In general the students make reasonable analyses of how the single components in their products are produced using the earlier described technique, i.e. identification of signs given by the component, where typical marks from the manufacturing process are identified and used to argue for how the part is produced. This is very much a graphical exercise where drawing capabilities are important. Students sketch the single components and preferably also the contours of the tools and dies used to make the components. Insight into assembly will in most cases come from the disassembly of the products done by the student design team. When dismantling the products they have to make notes so they can assemble the product again correctly. A part of the manufacturing analysis that often represent difficulties for the students is the account for where changes to the product is easy or difficult to make due to earlier investments in tooling or preferred materials and mode of production. The reason is that this requires a better insight into how industrial production takes place within a company. To supply the students with a minimum of this type of insight an excursion to one or two producing companies is part of the course curriculum.

Improved products

The quality of the final redesigned products should primarily be judged by the knowledge, understanding and skills that the students have acquired by making them. The course module is at first year and students cannot be expected to come up with improvements that will revolutionize the collaborating company. However, in a number of cases the results have been beneficial to the industrial client. At two occasions, the clients liked the outcome so much that they wanted to participate again with another product. After the redesign of a spinning bicycle another student design team was assigned to the redesign of a cross country ski-exercise machine. The redesign of a hospital bed was followed by the redesign of a patient lifting device. The redesign of the spinning bicycle was valued so much by the client, so many of the improvements proposed by the students are now implemented in the new version of the product. The redesign of the industrial tilting kettle to cut down on the large cleaning expenses proposed a radical solution where a large disposable plastic cup was to be used within the tilting kettle resulting in an almost elimination of the cleaning activity. It would furthermore introduce a new significant business model where the company would get a continued sale of plastic cups. The company liked the idea but feared that the conservative customers would not be in favour of the new design. Besides, there were technical challenges about heat transfer that needed to be investigated.

Apart from the concrete products resulting from the redesign there are other outcomes from the students that are valued by the industrial clients. One outcome is the use process analyses. The students have a unique possibility of get close to many users that can be difficult to approach for the industrial clients. Being a curious student opens many doors. Another outcome is the user network that the students can facilitate. The parcel handling within aircrafts is a good example of this. The students participated themselves in the parcel handling in the airport and managed to involve the workers in the design activity – a task that is much more difficult to approach for the employer.

Do the students use the methodology later in their studies?

Our experiences from bachelor projects (6th semester), final year projects (10th semester) and the project oriented course Holistic design (9th semester) are that the vast majority of students have acquired the product analysis method and use it again in their design projects. In particular this include the use process analysis and the product specification techniques, but also synthesis techniques from the other half of the course like morphology and comparison techniques are widely used. The worksheet technique is also widely applied in later student reports.

5 DISCUSSION AND CONCLUSIONS

Based upon the collected evidence from the empirical material we allow ourselves to conclude that the proposed product analysis method is very productive in building the students' knowledge, understanding and skills, and thereby prepare the students to be able to participate in and contribute to redesign projects in industrial practice.

If we discuss the course module Product Analysis and Redesign and our product analysis method in relation to the CDIO approach [1] we observe two interesting items. Firstly, Crawley et al. [1, p. 109] write, "*In the third-year and fourth year, students are given tasks of increased complexity and authenticity. For example, in the third year, they might be asked to redesign existing industrial products in order to improve performance or to decrease environmental load or cost.*" Product Analysis and Redesign is a *first year* course module of the bachelor programme Design & Innovation. This paper has shown that it is feasible to give first year students an existing product and a company contact person, and ask the students to carry through a redesign task. It is also very motivating for the students.

Secondly, with respect to the content of the redesign task Crawley et al. [1, p. 109] write, “*At this point, the students are able to make decisions using more situation-adapted strategies, selecting prototypes and simulation methods as needed to support the development process.*” In Product Analysis and Redesign the redesign task has focus on the conceive stage, and the proposed product analysis method encompasses an analysis of both the user side and the technical side of the existing product. The student design team has to analyse users and other relevant stakeholders as well as the product’s mode of action and manufacture in order to identify attractive and realistic improvement potentials.

Although our product analysis method is developed for the Design & Innovation bachelor programme, we believe it is highly relevant in other engineering disciplines. Engineers working in industrial practice, being engineering designers or technical discipline specialists, have to understand that in order to obtain a successful outcome of a redesign project it is paramount to understand needs and expectations of users and other relevant stakeholders. If a technical discipline specialist develops a new technical solution, which is not recognised as being better and upgraded in the users’ or another relevant stakeholder’s perspective, the solution has no value and contribution to the redesign project.

In modern engineering education we have to take socio-technical aspects into account. From a NSF workshop on engineering design in year 2030 [19, p. 1] we find: “*If the US is to capitalize on our research investments in micro-, bio-, info-, nano-technologies, as well as, conventional areas that continually lead to exciting technological advances, we must invest in engineering design tools and techniques in order to convert this research into commercial products.*” The NSF workshop formulates three content recommendations: engineering innovation, social-technical aspects, and design informatics. With respect to the socio-technical aspects, it is stated [19, p. 1]: “*Social-technical aspects: Basic knowledge regarding how humans and social dynamics influence design that involves multiple stakeholders with wide societal roles.*” Thus, from the NSF workshop we observe, that any engineer involved in developing research into commercial products has to have socio-technical competences, irrespective of his/her technical discipline area being “*micro-, bio-, info-, nano-technologies, as well as, conventional areas.*”

In the description of the product analysis method and its staging we have outlined some important elements relevant to formulating Conceive guidelines, and to support the CDIO syllabus. We conclude that the product analysis method proposed and verified in this paper is an important contribution to the conceive stage, is relevant for many engineering disciplines, and can be applied in engineering education from first year.

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HYPERION: An International Collaboration

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ABSTRACT

The Hyperion aircraft project was an international collaboration to develop an aerial vehicle to investigate new technologies with a focus on performance efficiencies. A delocalized international team of graduate and undergraduate students conceived, designed, implemented, and operated the aircraft. The project taught essential systems engineering skills through long-distance design and manufacturing collaborations with multidisciplinary teams of students located around the world. Project partners are the University of Colorado at Boulder, USA, The University of Sydney, Australia, and the University of Stuttgart, Germany. The three teams are distributed eight hours apart; students can relay select work daily so that developments can "Follow-The-Sun". Select components are manufactured and integrated both in Stuttgart and Colorado, giving the students an opportunity to learn multifaceted design tactics for manufacturing and interface control. Final flight testing was conducted by the global team in Colorado during the month of April 2011.

KEYWORDS

Global design, international teamwork, aircraft design, green aviation.

MOTIVATION

There is a growing trend of global, multi-company collaboration within the aerospace community. With the growing maturity of information technology and ever-increasing complexity of modern engineering and education, many parent companies form partnerships with specialty teams in order to facilitate rapid development across all subsystems of a project. For example, the Boeing Company purchases roughly 65% of the newly developed 787 Dreamliner airframe from outside companies [1]. In a field where work is traditionally performed by small, localized teams of engineers, these complex global projects present new challenges for overcoming cultural differences, language barriers, and bureaucracy. As a result, project management is more significant than ever before. Figure 1 shows an example of Boeing's global distribution and breakdown of work performed on the 787 Dreamliner.

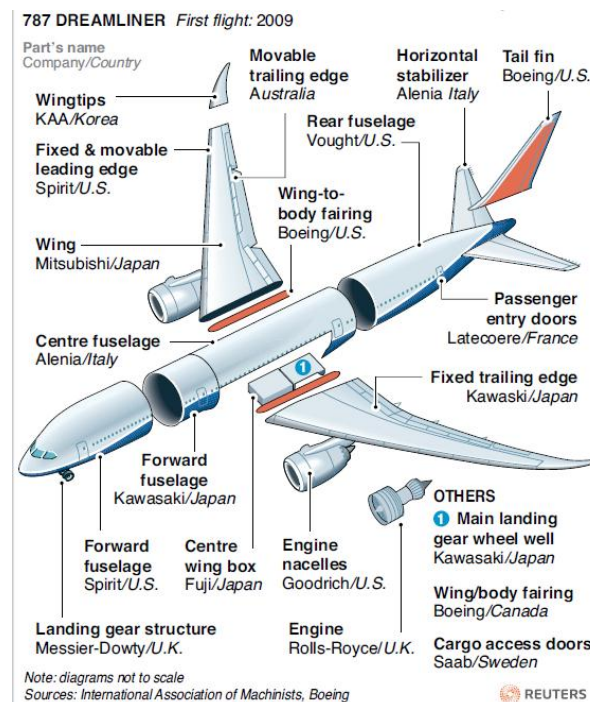


Figure 1. Boeing 787 Global Work Breakdown Structure [1].

Aside from project planning and logistics, there is also a movement towards green aviation and improving the sustainability of the products produced in the aeronautics field. Green aviation is of global significance, with the Asian commercial airline industry flying more passengers than the U.S. in 2009 [2]. According to a 2010 NASA report, the U.S. commercial airline industry is projected to fly 1.21 billion passengers each year by 2030 [2]. The increase in fuel consumption, associated air pollutants, and noise from this growing industry is a mounting concern. Therefore, NASA has issued a new set of industry challenges including reducing fuel burn and nitrogen oxide emissions by 50% by 2020 and restricting the nuisance noise footprint produced by aircraft to the airport boundary [2]. These challenges are being directed to the aerospace industry as a whole, with intended performance improvements in all aircraft subsystems and successful implementation of green aviation technologies.

With both of these industry trends set to define a large focus of the next 20-50 years of the aerospace industry, educating the next generation of engineers who will be responsible for addressing these challenges is of paramount importance. While aerospace engineering studies typically focus on engineering fundamentals, courses lack opportunities for students to gain experience in extensive systems engineering principles, manufacturing, and project management. While many universities have capstone senior design courses set to instill these values, modernizing the learning experience to better represent the global workings and pains in industry has habitually been omitted due to the perceived level of scope attainable in 2-semester academic projects. Efforts to train students in the global design effort have been reported before, and they were mainly limited to virtual computer design studies and did not include delocalized manufacturing [3].

Design engineering is based on customer requirements. These requirements have to be communicated to and continuously discussed by all the team members. To communicate well, both verbally and in writing, is essential for project success. Team members share information, exchange ideas and influence attitudes and actions as well as understanding of the issues at task. Communication is also required to develop interpersonal relationships, inspire team members, and handle conflicts and different opinions. Most students are trained in communication on a local level where face-to-face meetings are common. In a global team, members may not know each other personally or have the possibility to pick up the phone at any point of time to clarify an encountered concern. This requires at the onset a very clear description of the requirements and the development of interface documents. The English language used can no longer be casual and the underlying innuendos of individual words have to be evaluated carefully from a linguistic point of view. This is most important when there is different cultural interpretation at work. The same word may have different meaning for people from different cultures and schooling in the language, especially when English is not their first language. Although the technical terms may be understood, the more descriptive wording may lead to an incomplete or filtered communication. In different cultures the educational program itself may provide students with different skill levels in similar fields of study [4].

Because of their academic nature, student projects are particularly prone to communication difficulties. Utilizing a managerial structure of the teams with defined responsibilities, decentralized decision making, and complex interfaces allows for multiple communication modes of failure. The person issuing a message with a purpose normally encodes that communication based on a personal bias. The bias is rooted in encoding the message based on the environment, culture, and knowledge of the sender. A recipient is biased by one's own hearing, listening, reading, language skills, ethical values, mood and motivation. Sender and receiver both have preconceived ideas, references, and interests in the project contributing to a certain noise level in the communication. The choice communication medium is known to have an impact on the communication success. One element that is absent in virtual communication is body language which has an impact on the decoding of a message by the recipient.

In an engineering design project, engineers work iteratively at the beginning of the project in order to come up with the best design solutions for the top level project requirements leading to system requirements that get "frozen" allowing a transition to manufacturing. That design phase is extremely dynamic and prone to misinterpretation which may not be caught on time and which could lead to failure of some kind of the project. Design choices have to be negotiated by the delocalized team members. All the technical analyses have to be done with the same software, comprising even the same version of the software.

The Hyperion project, besides being a challenging technical project, is designed to train students in reducing the communication noise inherent in all communications and prepare them to become global engineers.

INTRODUCTION

At the University of Colorado at Boulder during the summer months of 2010, a small team of continuing education (B.S./M.S.) aerospace engineering seniors were challenged to develop a global academic project that would assess the feasibility of simulating known pains of the modern global industry. This undertaking became known as the Hyperion project. The Hyperion project was to span 2 academic semesters during 2010-2011, consist of a minimum of 3 delocalized international student teams, and conceive, design, implement, and operate a completely new type of aircraft. In essence, the proposed academic project was to incorporate two major elements:

1. A global project management element with three participating teams located on three different continents, and
2. A technical design, implementation, and operation element to teach systems engineering principles required in aeronautics.

To satisfy the global project management aspect of the project, the *Follow-The-Sun* (FTS) concept was identified as a promising model for improving the productivity of delocalized teams. The FTS concept revolves around three teams, spread eight hours apart, who relay their work every eight hours, realizing 3 working days in a single 24 hour period. The University of Stuttgart, Germany and the University of Sydney, Australia both agreed to participate with the University of Colorado at Boulder (CU), U.S.A in the experimental project. In addition to the stated goals, the Hyperion project is intended to foster global relationships among aerospace engineers and expose members to different philosophies and techniques. Integral to achieving this is the exploration and adoption of technologies that facilitate the sharing of ideas, real-time collaboration and interaction.

The blended-wing-body (BWB) NASA/Boeing X-48B aircraft was set as the inspiration for the aircraft design. The BWB architecture was chosen as the initial design focus, as it is one of industry's leading fuel efficient platforms demonstrating the latest developments in green aircraft technology. The X-48 BWB concept, shown in Figure 2, was originally designed by Liebeck, Page, and Rawdon in 1998 [5]. The airframe is a merger of efficient high-lift wings and a wide airfoil-shaped body, causing the aircraft to generate lift in its entirety and minimize drag, thereby increasing fuel economy. It is expected that the aerodynamically efficient BWB design will reduce fuel consumption up to an estimated 20% [6]. Unlike conventional tube and wing architectures, the optimal design of a BWB vehicle requires a much more tightly coupled systems engineering analysis, including aerodynamic and structural analysis of the vehicle, flight mechanical design, management of mass properties, and the development of modern control systems. The use of composite materials throughout the construction of the vehicle was also to be maximized in order to increase the experience and exposure of the students to the challenges and techniques used in modern aerospace manufacturing.



Figure 2. Boeing/NASA X-48B [3].

PROJECT DESCRIPTION

The following Hyperion project description pertains primarily to the global engineering and project management experience of the project. Further details on the technical aspects will become available in future publications.

Incubation

The Hyperion project began in June of 2010, when all three international universities gave the project a green light. This was made possible by the collaboration of Professors Jean Koster of Colorado, Claus-Dieter Munz and Ewald Krämer of Stuttgart, and KC Wong and Dries Verstraete of Sydney. Development began with the initial formation of the project goals, scope, and preliminary work breakdown structure (WBS), preliminary schedule, and acquisition of project funding. With each University's academic semesters starting and ending on different dates, careful consideration had to be taken into account when planning the WBS and schedule. Although the leadership of the project was in the hands of the CU graduate students, The University of Sydney was first to form their student team and begin design work for the aircraft. The project commenced the first week of August, 2010, before the University of Colorado and the University of Stuttgart academic school years began and all the student teams were assembled. In that effort, the first subtask handled by Sydney was the aerodynamic configuration design and analysis of a blended-wing-body flying wing geometry aircraft.

Project Requirements

The top-level project requirements, shown in Table 1, were derived and driven primarily from the two project elements, incorporation of the hybrid engine, and the Boeing/NASA X-48B architecture.

Table 1
Top-Level Project Requirements

Req. #	Top Project Requirement Description
0.PRJ.1	The Hyperion Project shall conceive, design, implement, and operate a blended fuselage and wing aircraft.
0.PRJ.2	The aircraft shall have a wingspan between 1.8 and 3 meters.

0.PRJ.3	The Hyperion project shall consist of a global team network of 4 teams: Undergraduate and graduate teams at University of Colorado at Boulder, a combined graduate/undergraduate team at The University of Sydney, AU, and a graduate team at the University of Stuttgart, GER.
0.PRJ.4	The Hyperion aircraft shall have a lift to drag ratio no less than 20.
0.PRJ.5	The Hyperion aircraft structure shall have a composite material outer skin and internal structure.
0.PRJ.6	The Hyperion aircraft shall have a modular design, allowing for shipping of the vehicle internationally without necessitating a freight shipping classification.
0.PRJ.7	The Hyperion aircraft shall be powered by a hybrid propulsion system, consisting of an internal combustion engine and an electric motor.
0.PRJ.8	The Hyperion aircraft shall be remotely controlled by a ground operator using an onboard vision system.
0.PRJ.9	The Hyperion aircraft shall have a maximum of 8 actuated control surfaces.
0.PRJ.10	The Hyperion aircraft shall be propeller driven.
0.PRJ.11	The Hyperion aircraft shall be capable of takeoff and landing on a 750ft runway.
0.PRJ.12	The Hyperion teams shall communicate regularly using video conferencing, online document sharing, and teleconferencing.
0.PRJ.13	All measurements of systems shall be in SI units.

Schedule

Compared to a conventional academic project, the Hyperion schedule was orders of magnitude more complicated to develop as special consideration had to be made to accommodate the out of sync university's semesters. The Sydney semester began first, with Colorado's a close second, and Germany starting third in mid-October. Figure 3 shows a simplified schedule as well as each University's semester dates and overlap.

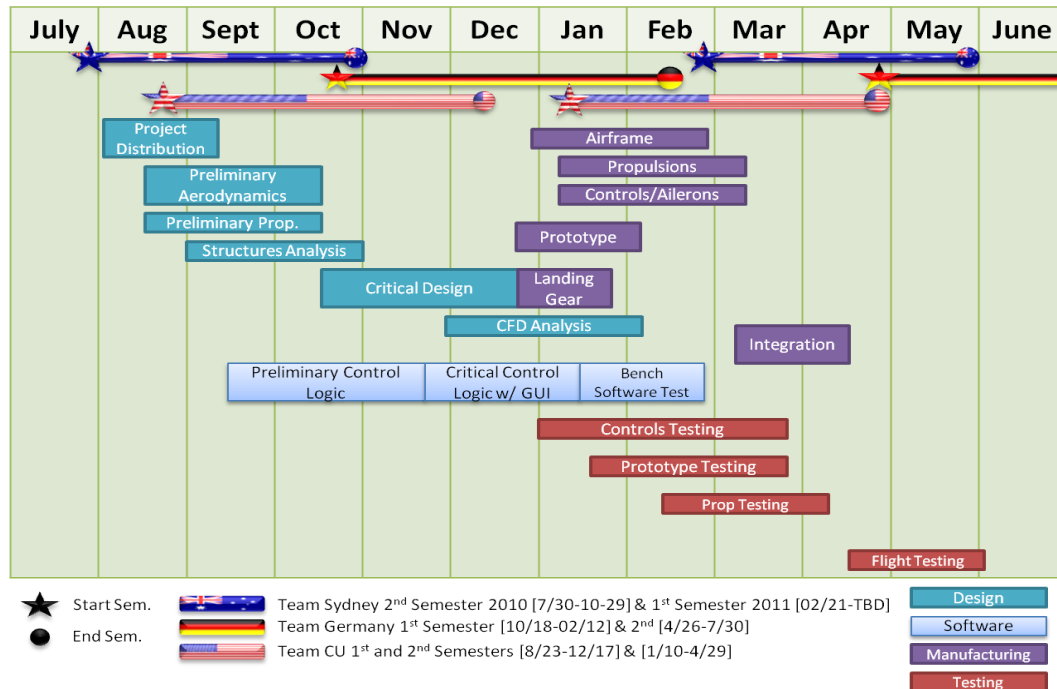


Figure 3. Simplified Project Schedule.

The schedule was based on the University of Colorado's Senior Design Course timeline, which encompasses an entire project experience over the span of 2 semesters. The project is divided into two primary phases, in sync with the CU semester schedule.

The first semester, or phase of the project course, is focused entirely on design, analysis, and prototyping. Starting with a statement of work and the top-level requirements, students begin the semester organizing themselves, defining system and sub-system requirements, developing team and work break down structures, and conducting preliminary design. During the first design phase of the project, there are two major decision gates based off of industry practices, a Preliminary Design Review (PDR) and a Critical Design Review (CDR). These reviews hold several purposes, including:

1. Standing as milestones for the project development
2. Allowing students to gain experience with professional public speaking
3. Forcing students to defend their design work using critical thinking and technical analysis
4. As an internal 'checks and balances' for the team members and subsystems to ensure consistency and compatibility, and
5. Mitigate project risks by providing outside feedback on design decisions

At CDR, the entire design development of each subsystem of the project is to be complete and frozen in terms of future development. This serves as a critical milestone for the teams to work towards.

The second phase of the project encompasses the manufacturing, integration, and testing aspects. Each component must be manufactured, tested at a subsystem level, integrated to the system level, and tested again to both verify and validate all project requirements.

End of project deliverables include:

1. An oral presentation
2. A flight demonstration showcasing the advances in technology
3. The Hyperion Aircraft, itself, with operations manual
4. A comprehensive Project Final Report (PFR) covering all engineering, documentation, and contacts tied directly to the project,
5. (In the event of system failure) A technical report documenting test findings for the root of the system failure.

The project deliverables were set to ensure both systems engineering principles and project management are projected throughout an exciting educating experience. Students are able to gain real world technical experience, not by designing, but by building their creation in a hands-on environment. Seeing manufacturing processes and learning to understand the technical limitations of production are an extremely valuable experience for every engineer.

The student team in Sydney comprised of 3rd and 4th year (of a 4-year BE (Aeronautical) program) undergraduate students as well as 1st year volunteers who helped out in the construction of the wind tunnel model. As the senior students enrolled in the project as an elective unit of study, the local deliverables in Sydney included reports or hardware for aerodynamic testing.

The activities of the students in Stuttgart were organized within the framework of diploma theses. Here, the usual deliverables are

1. An oral midterm presentation,
2. An oral presentation at the end,
3. A written diploma thesis at the end.

For the Hyperion project the listed deliverables were accompanied with short meetings on a weekly basis with the advisers to keep them updated on the project. The diploma theses which shall be written on the Hyperion contributions will not only contain a description of the performed scientific and technical work, but also include comprehensive information about the global project objectives and the contributions and validations performed by the individual student.

Global Project Team

The Hyperion project was divided into 4 student teams:

1. A Graduate team from The University of Colorado
2. A Graduate team from University of Stuttgart
3. A graduate/undergraduate team from The University of Sydney
4. An undergraduate team from The University of Colorado

Projects at the academic level are notably different from industry due to two primary factors. Collegiate students have varying class schedules with respect to one another, compared to industry teams' steady work hours. This makes scheduling the necessary daily meetings of a college team very difficult for the students to internally manage. A second notable difference is that students who work on an academic project are motivated by a grade, not salary. Their

work is largely voluntary rather than mandatory. This requires a more difficult approach to project management, as the monetary motivational leverage is not available to the manager. Fortunately students have another strong motivational driver—passion.

The architecture of the Hyperion project team is shown in Figure 4.

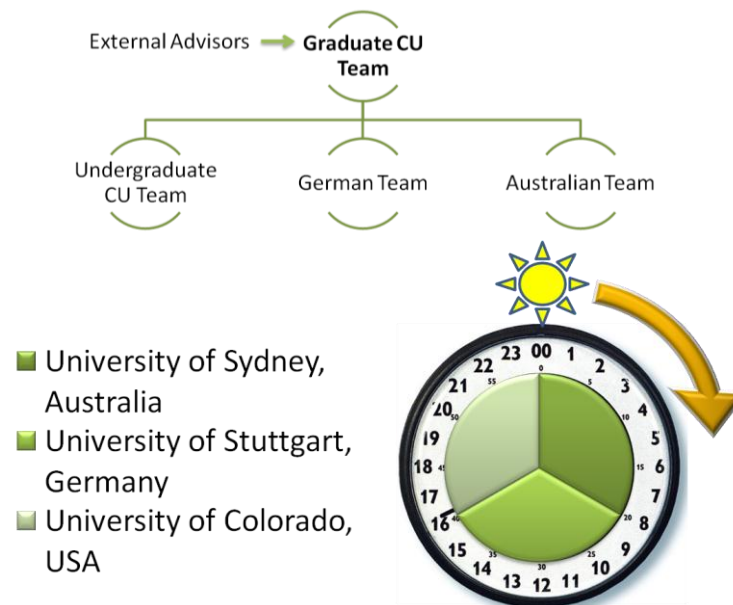


Figure 4. Hyperion Team Architecture

The goal of the team design is to expose senior and graduate students to the need for collaborating in a global industry with design offices and manufacturing facilities around the world. Colorado's graduate team leads the development of the project and distributes and incorporates work from the CU undergraduate team, the German and Australian teams through the use of Configuration Control Documents. These living documents are essential to maintaining consistency and direction of the designs. The requirements on quality of these documents are very high due to several factors. Tasks, revised at the end of workday for the next team, must be defined with great precision and extreme clarity. The English words may have subtle underlying meanings that may be interpreted differently by different cultures, work procedures in different cultures may be different, and teams must agree on using the same software packages as well as the same versions of software. Each team works eight hours and updates the configuration control document, then passes it to the next team to work eight hours, and so on. The model allows packing three regular working days by three teams on different continents into 24 continuous hours, accelerating project development by the "Following The Sun" principle. Robust internet communication is essential. Students are challenged to communicate effectively and efficiently on a daily basis across all subteams.

The Graduate University of Colorado Team

The graduate team focused on all of the integration, management, and internal designs of the aircraft. The master designs of the aircraft are archived in Colorado, for quality control and logistics. The team was selected based on an individual's contribution to the skill sets identified as being critical to the project.

Each of the 13 CU team members was given ownership to single subsystem or managerial position of the project, which trains every student in leadership skills. Table 2 shows the breakdown of ownership amongst the CU graduate team. Students work toward a degree in Aerospace Engineering Sciences (AES), Electrical Engineering (EE), and Master in Business Administration (MBA).

Table 2
Graduate CU Team Members & Leadership Roles

Name (Background)	Primary Responsibility	Secondary Subteam(s)
Alec Velazco (AES)	Project Manager	Business, Manufacturing
Eric Serani (AES)	Configuration & Systems Manager	Controls, Propulsion
Derek Hillery (AES)	Systems Engineer	Controls
Cody Humbargar (AES)	Propulsions Lead Engineer	Aerodynamics, I&T
Scott Balaban (AES)	Structures Lead Engineer	Aerodynamics, I&T
Chelsea Goodman (AES)	Controls Lead Engineer	CAD, I&T
Richard Zhao (EE)	Electrical Lead Engineer	Controls, I&T
Julie Price (AES)	Mass Properties Manager	CAD, Controls
Andrew Brewer (AES)	Integration & Testing Lead Engineer	Electrical, Structures
Derek Nasso (AES)	Aerodynamics Lead Engineer	Mass Properties, Structures
Mikhail Kosyan (AES)	Manufacturing Lead Engineer	CAD, Structures
Mark Johnson (AES)	CAD Lead Engineer	I&T, Structures
Thomas Wiley (MBA)	Business Operations Manager	I&T, Accounting, International

The idea behind assigning team leads is to instill a sense of ownership over that particular item or subsystem of the project. That allows for each team member to be involved directly, and allows the team as a whole to divide and conquer. Each sub-team lead is responsible for organizing their own respective meetings with secondary members to delegate and micro-manage the work effectively. This allows the Project Manager to efficiently delegate work and easily identify the performance of the team.

The graduate CU team holds a formal 1-hour weekly Configurations & Systems meeting where all sub-teams report on the progress, problems, and plans of their system development. The meeting also serves as an opportunity for external advisors, sponsors, and the customer to provide input and guidance for problem solving strategies and risk mitigation. In addition, weekly meetings are held between CU/Stuttgart, CU/Sydney, and Stuttgart/Sydney. The agenda is similar with updates on progress, problems, and plans.

During the second phase, the project effort must shift from design to manufacturing, integration, and testing.

The University of Sydney Team

Of the three international Universities, The University of Sydney's semester scheduling was the most significantly different from the other two universities. Not only did Sydney's semester begin before both Colorado's and Stuttgart's, it was also the second semester with regards to their academic year. This early beginning drove the early decisions with regards to the work breakdown of the project.

In order to maximize the contributions by the Sydney team, they were given the task to perform the preliminary aerodynamic trade studies regarding the geometric shape of the aircraft. In this manner, the work could begin immediately, without waiting for the Colorado and Stuttgart teams to be formed. By the time the Colorado team was fully structured, Sydney had several preliminary models complete for designs to be evaluated and discussed between all the teams.

After the design work was complete, the efforts in Sydney shifted to produce a ½ scale static wind tunnel model of the Hyperion aircraft to be tested at the University of Sydney's 7 x 5ft wind tunnel. This work was primarily performed during their respective summer break. Students ranging from first year engineering students to 4th year students participated in building multiple models and performing aerodynamic testing on the aircraft. This led to preliminary sub-scale flying model to verify stability and control characteristics of the design concept, followed by the wind tunnel testing of a half-scale model, which verified the confidence of the earlier CFD analyses, and provided guidance to set up the full-size flight test prototype. Figure 5 shows the half-scale model installed in the wind tunnel.



Figure 5. Half-scale wind tunnel model installed in the 7 by 5 ft wind tunnel in Sydney.

Table 3 denotes the members and responsibilities of the University of Sydney team.

Table 3
The University of Sydney Team Members & Leadership Roles

Name	Responsibilities
Kai Lehmkuehler	International Aerodynamic Lead / Team Manager / Wind tunnel testing Lead
Matthew Anderson	Performance Engineer / Wind tunnel model construction and testing
Joshua Barnes	Structures Engineer for wind tunnel model / CAD
Byron Wilson	Structures Engineer for wind tunnel model / CAD
Andrew McCloskey	Sensors and Autopilot Engineer

The University of Stuttgart Team

Last to form and begin their semester, the University of Stuttgart team was brought on board the project after the preliminary trade studies had been performed on the shape of the aircraft.

Similar to Sydney being well suited for aerodynamics studies, the German team brought a unique set of skills in computational fluid dynamics (CFD) and composite manufacturing which were absent on the Colorado and Sydney teams. One student took the responsibility to serve as the local project manager and primary contact between the international teams.

The CFD computations performed at Stuttgart served mainly three purposes: first of all was the computation of a half-scale model with symmetric flow conditions. These results were used as a cross check for the results obtained at Sydney during the preliminary design process. The second purpose was the assessment of the engine integration and its impact on the aerodynamic characteristics of the aircraft. The third task was the investigation of the manoeuvrability of the aircraft. Several configurations with control surface deflections were investigated for symmetric and asymmetric flight conditions to evaluate the effectiveness of the flight control system. The aerodynamic derivatives obtained in this part are needed by the team responsible for the flight control software.

Table 4 denotes the Stuttgart team members and responsibilities.

Table 4
Graduate Stuttgart Team Members & Leadership Roles

Name (Background)	Primary Responsibility	Secondary Subteam(s)
Holger Kurz (AES)	Stuttgart Project Manager	Structures, Manufacturing
David Pfeifer (AES)	Aerodynamics Engineer	CATIA Contact, CFD
Matthias Seitz (AES)	Aerodynamics Engineer	CFD Engineer
Martin Arenz (AES)	Propulsions Lead Engineer	Aerodynamics, I&T
Baris Tunali (undergrad)	Manufacturing	
Jonas Schwengler (undergrad)	Manufacturing	

The Undergraduate University of Colorado Team

With no previous project experience, the undergraduate team in Colorado was formed per the requirements of the capstone aerospace senior design course (ASEN4018/4028). Eight students were assigned to the team, all seniors in aerospace engineering. In order to maximize the undergraduate teams learning experience the undergraduate team operated largely independently, with their primary project goal to design, build, and operate the hybrid propulsion system for the Hyperion aircraft. The hybrid propulsion system was considered a stretch goal for Hyperion. Taking ownership of the propulsion subsystem allowed for minimal overlap and dependency with the rest of the aircraft's design development. One graduate team member assumed the liaison position with the undergraduates. The undergraduate team was given a set of requirements recognized in an interface document for their propulsion system to meet, which included dimensions and performance criteria. This allowed for the Stuttgart, Sydney, and Graduate Colorado team to move forward with the designs without constant involvement with the senior CU team. In the event the undergraduate team fails to produce a working engine, a basic electric motor propulsion system was designed to be used as an off-ramp for the airframe.

This allowed for the senior team to have an adequately scoped project, while minimizing the risk to the international Hyperion project failing being able to fly due to lack of engine delivery. In the same sense the success of the undergraduate team needed to be independent of success or failure of the graduate team designing the Hyperion airframe.

The undergraduate CU team is structured under the same principles as the graduate team, with team leads and specific subsystem ownership assigned to individuals, shown in Table 5.

Table 5
Undergraduate CU Team Members & Leadership Roles.

Name (Background)	Primary Responsibility	Secondary Subteam(s)
Gavin Kutil (AES)	Project Manager	Aerodynamics
Gauravdev Soin (AES)	Electrical Systems Engineer	Controls
Corey Packard (AES)	Mechanical Systems Engineer	Aerodynamics, Mechanical
Michaela Cui (AES)	Chief Communications Liaison	Software, CAD
Brett Miller (AES)	Chief Financial Officer	Controls, CAD
Tyler Drake (AES)	Chief Safety Officer	Mechanical, Electrical
Marcus Rahimpour (AES)	Chief Test Officer	Controls, Structures
Arthur Kreuter (AES)	Chief Equipment Specialist	CAD, Software

Work Breakdown Structure

The work breakdown structure (WBS) of the Hyperion project served as a challenging logistics problem for students inexperienced in project planning. The question, “who can do what and when?” is easier to identify in an industry environment, where employees are hired for specific jobs and titles. For a student team comprised of varying degrees of skill-sets and schedules around the world, there is little time to waste in determining who is responsible for each subsystem and deliverable. There were two primary drivers for the WBS distribution, *skills* and *schedules*. In determining which teams were assigned tasks and ownership in the project, the skill-sets of each university were weighed with respect to one another to identify strengths. The schedules were then evaluated to determine what work correlated with the development stage of the project. Since Australia began their semester first they were given the responsibility of the aerodynamic shape of the aircraft, the preliminary configuration design, the sizing of the control surfaces and contributing to weight and balance analysis for stable flight. Germany were given the lead in developing the wingtip and vertical stabilizer designs, CFD analysis, and manufacturing of the center body skin. The broader Colorado graduate team lead the structures, electronics, controls, software, mass properties management, financial operations, and overall project management.

The development of the logistics of collaboration was a major undertaking. The skills of all the participating international students had to be incorporated in the work distribution management. The WBS was first split in 5 categories which followed the systematic order of the project’s development, with the exception of management which was constant across the 9 months. The top level WBS is shown in Figure 6. From this WBS and the items identified as the top level systems of the project, further more in-depth WBS were developed, which were then decomposed further.

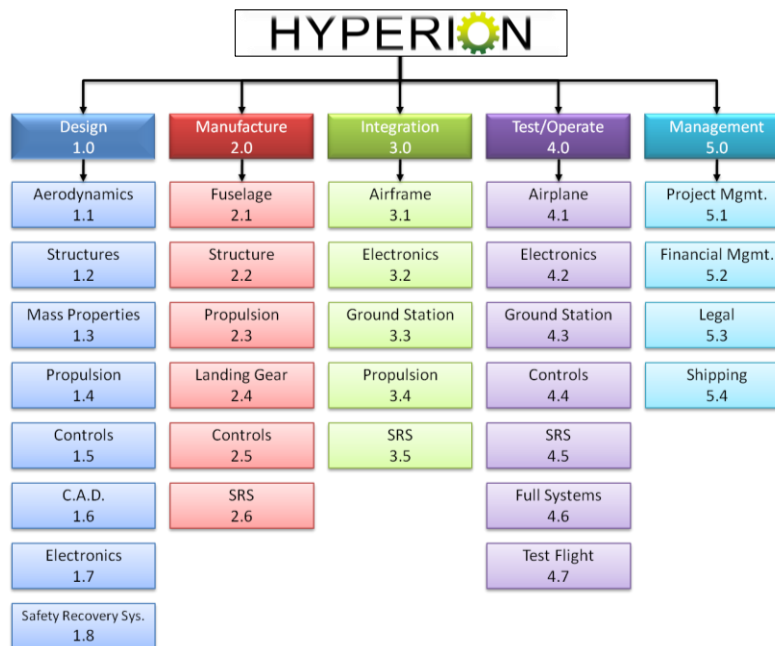


Figure 6. Top-Level Work Breakdown Structure

The systematic approach to the WBS resulted in an effective use of team skills, maximizing production and minimizing risk.

Budget

As students, the labour cost to design and manufacture the systems necessary to fly Hyperion is negligible. Further, the student teams have unparalleled access to resources, both intellectual and physical. In traditional industry groups, considerable money is spent to leveraging these resources. These include contact with professors and industry engineers as well as university owned hardware like computers and manufacturing equipment.

Despite the economic advantages of working with university engineering teams, there are costs that must be absorbed in order to produce the aircraft. These include materials and components, communication, travel, and access to testing facilities. Large contributions were made by different industry leaders to help defray many of these costs.

Strict oversight of the budget is crucial to realize the ambitious goals of the Hyperion project. Much like the opportunity to learn global collaboration and CDIO skills, learning how to manage financial resources will help prepare the students for real-world project management.

A budget was carefully developed to allocate financial resources appropriately and each team's purchases are closely tracked. This careful budgeting has afforded additional opportunities to test design alternatives and material characteristics. Figure 7 shows how funds have been allocated across subsystems based on a percentage of each university's total allotted funds.. The Sydney team was not able to secure any industry funding due to a depressed local industry situation. Sydney's funding stems from support through the School of Aerospace, Mechanical and Mechanical Engineering (lab, workshop, and wind tunnel resources), the school's R.W.

McKenzie Resource Centre for Teaching and Research in Aeronautical Science and Technology (sensors), CU (wind tunnel model), and the academic advisors' maintenance funds.

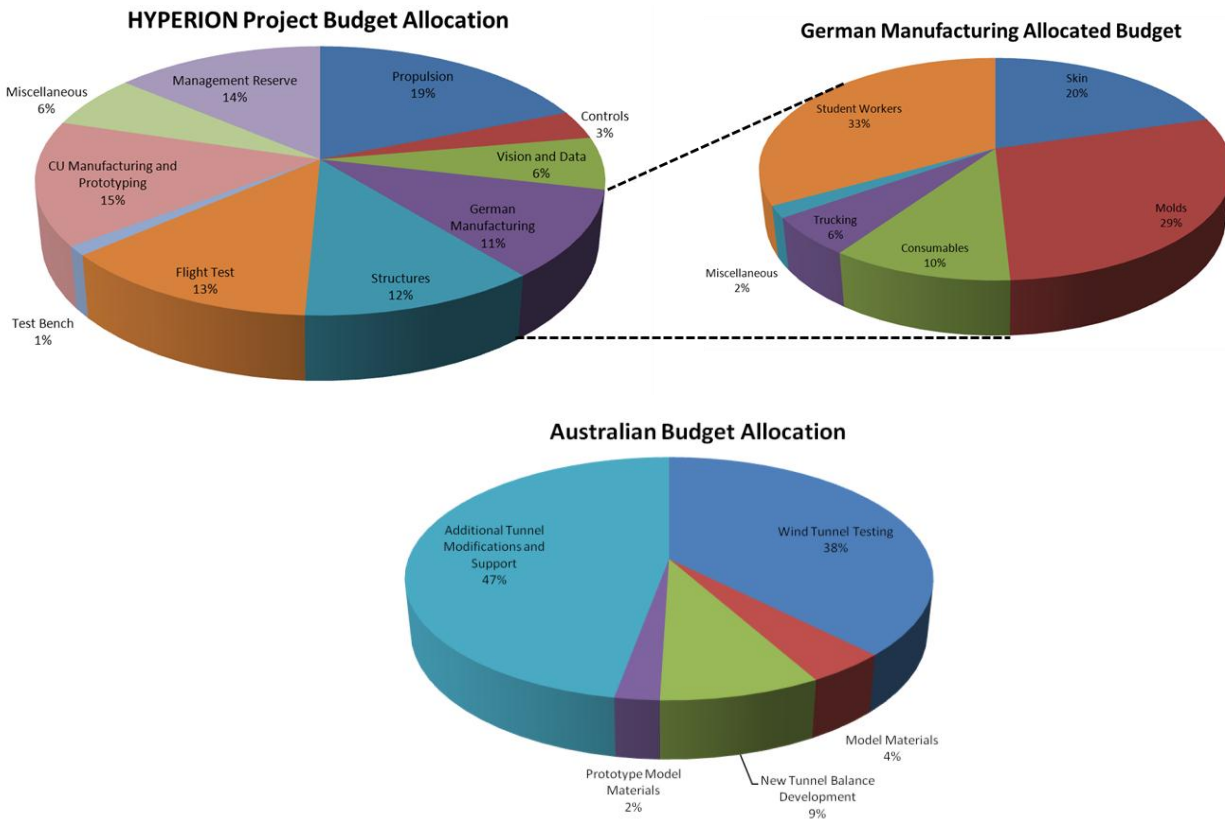


Figure 7. Budget Allocation

The procurement process was closely monitored to ensure that parts were ordered on time and from the appropriate vendors. Care was also taken so that parts did not arrive too early and risk loss, accidental damage or obsolescence due to changes in design. Figure 8 shows procurement activity over time in both a daily and accumulative way. This graph closely resembles manufacturing activity.

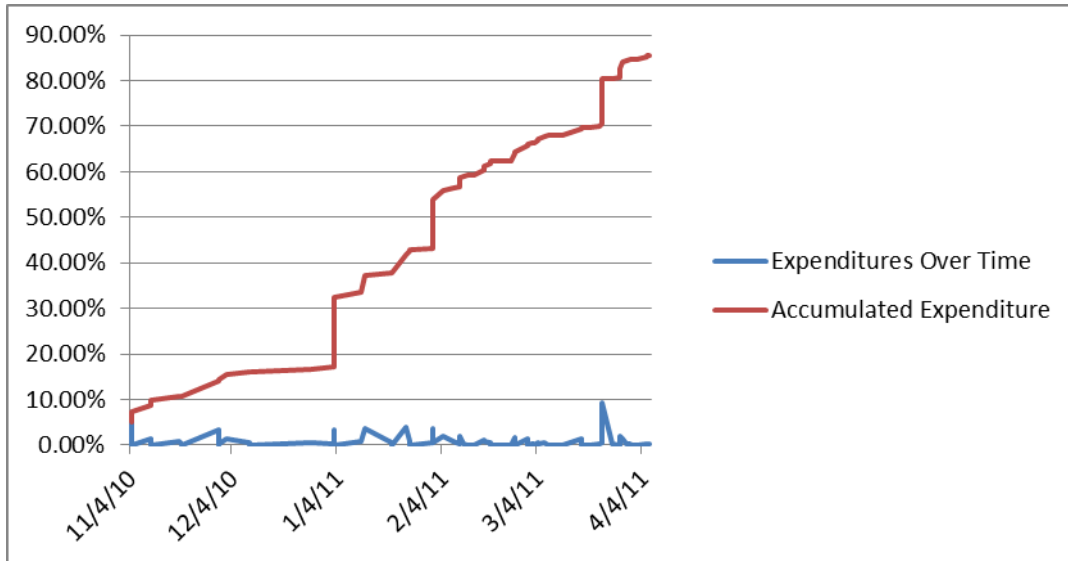


Figure 8. Expenditures across time

Human Resources

The team tracked the total number of hours worked per week which helped monitor those tasks that were running behind and whether or not deadlines were being met. This data also helps show how industry is able to benefit from partnering with academia. The three graduate teams combined worked a total of 6,335 hours over two semesters. Using salary data from the US Bureau of Labor Statistics, this work would have cost \$259,489 in wages. Not included in that budget number are the conceivable consulting fees of the many faculty members advising the students. Figure 9, below, shows the hours worked each week over time. The drop midway through corresponds with semester break during the holidays.

The steady climb, drop and resumed climb correspond with the different phases of the project. Week 12 was the end of the semester for Colorado students which include deliverable deadlines before break. Many students departed for the holidays and resumed increasing amounts of work once the spring semester began. Of note is the saw-toothed profile of student work.

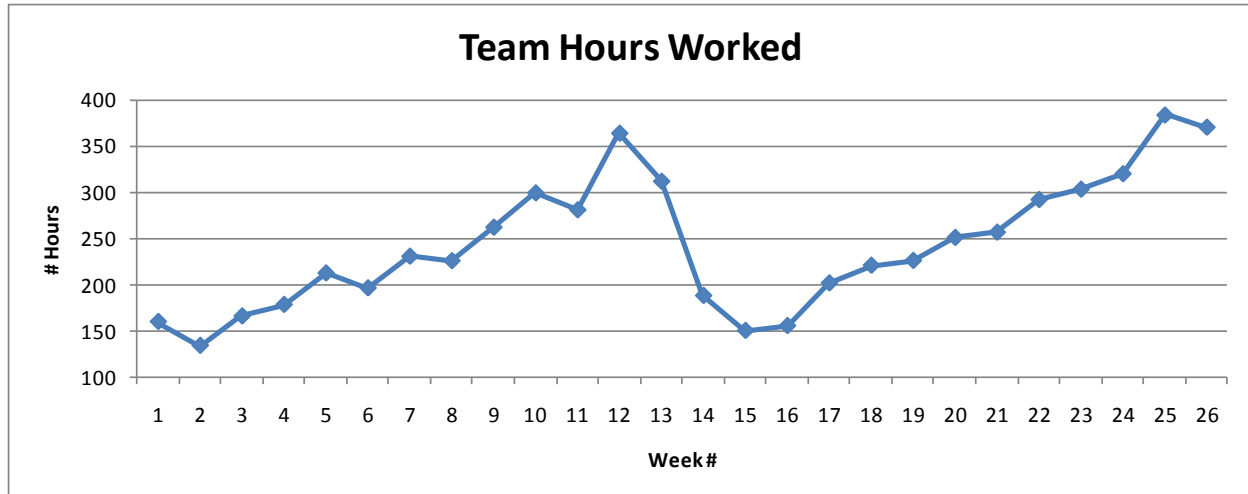


Figure 9. Graduate Hours Worked

BEST PRACTICES

Communication

The Hyperion project is a great lesson in international design collaboration. Coordinating the efforts of multiple international teams, each with their own language and culture, is complicated at best. These soft constraints in turn are amplified by the constraints of different time zones and challenges of international shipping.

Information management was perhaps the most critical aspect of the Hyperion project. With multiple teams operating in separate locations, perpetual contact is necessary to make sure efforts are in sync. Fortunately, the options provided by the internet have enabled all three teams to share documents, test aerodynamic models and maintain synchronization. Weekly conference calls were held via Skype™, allowing for both audio and visual communication. Documents were shared through cloud computing using Huddle™.

An example of this successful communication and work flow can be found in the aerodynamic design experience. Engineers in Australia would work with model dimensions and upload their CAD files to the cloud and verbalize ideas over Skype™. This allowed for seamless continuation in Germany, where the Stuttgart team refinement work could take place. Towards the end of the Stuttgart work day, updated files and ideas would be shared with the Colorado team who would add their expertise to the aircraft's design and check progress with the requirements. After a day's work, they in turn would post their contributions on Huddle™, discuss changes over Skype™, and the Australia team would pick up where Colorado left off. This constant work allowed for three days virtual CAD work to be completed in 24 hours.

The large number of Hyperion members makes communication intricate. Between the three universities there are 32 students and professors. Adding the 20 industry and academic contributors brings the number to 52 and the possibility for 1,326 one on one communication channels. With so many opportunities for communication, a small percentage of miscommunication is already a large number of miscommunications! To mitigate or reduce the occurrence of miscommunication, interface and configuration control documents were

implemented to be able to track and manage critical pieces of information on a daily or weekly basis.

The CAD design work was accelerated effectively by using Follow-The-Sun techniques. With most student projects only comprising 1-2 CAD engineers, the Hyperion project was able to employ roughly 10 students with CATIA design work each week during the design phase. This allowed for far more design work to be completed in a very short amount of time. The entire structure, skin, landing gear, and propulsion system was designed in roughly 6 weeks. This included structural analysis and sizing of the ribs, spars, skin, landing gear attachment points and elements of the propulsion system, either by formulaic calculations or through CATIA with contributions from each university. The Hyperion design and model is shown in Figure 10.

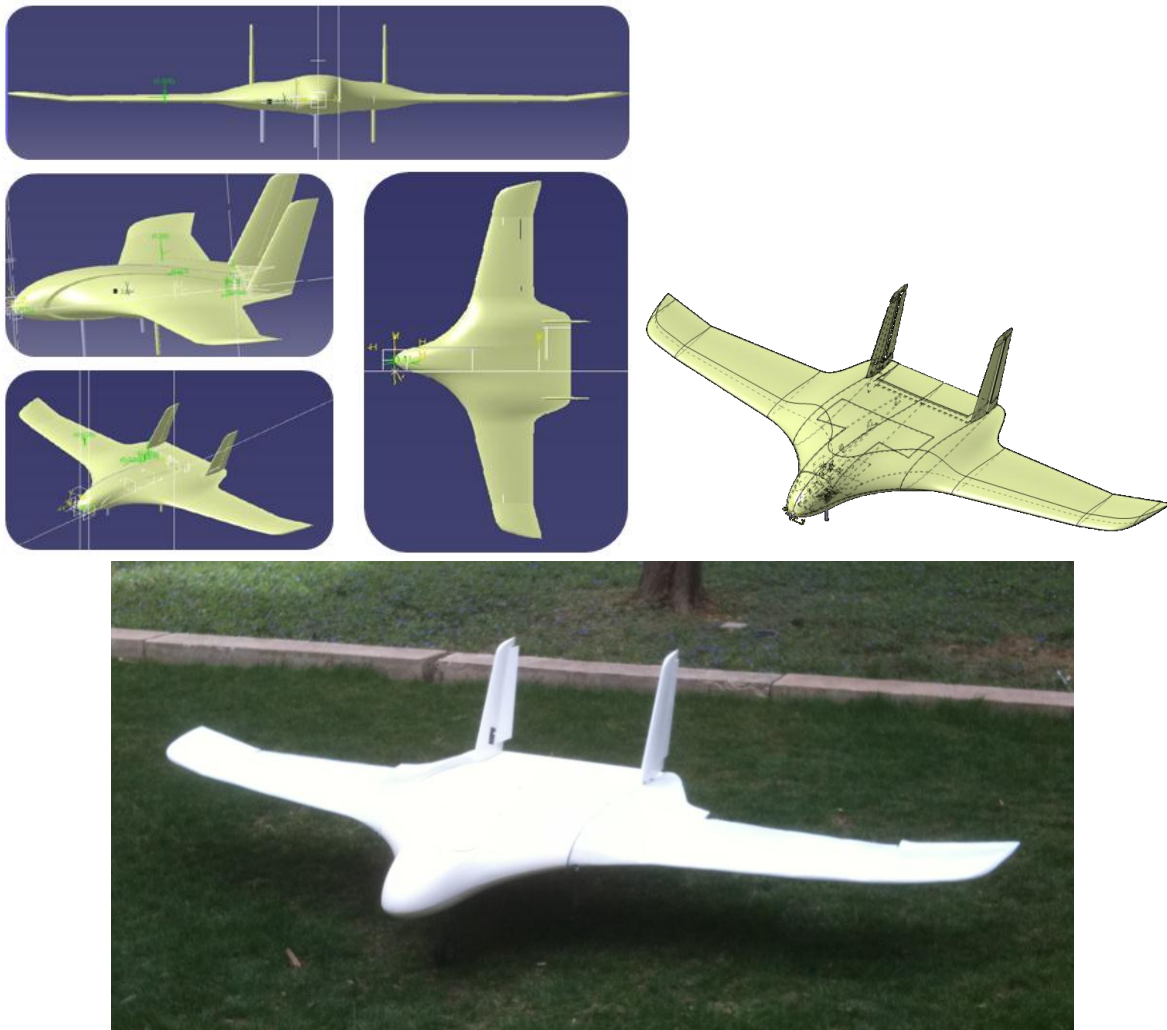


Figure 10. The Hyperion Aircraft

None of the collaborative CAD work could have been possible, had each university not had the same CAD program and version. Determining early on in the project which software to use proved highly valuable.

Manufacturing

The problems faced by Boeing's Dreamliner team highlight the complexity of international manufacturing [7]. The CU-Hyperion team has benefited from access to different points of view as well as facilities otherwise unavailable. These include engineers who have extensive experience with the X-48 design, advice from experienced professionals with international collaboration knowledge, as well as fabrication and testing facilities in the Australia, Germany and the United States.

The logistical constraints imposed by time and distance are another significant problem caused by international manufacturing. As Boeing experienced, millions of dollars' worth of sub-assemblies will sit idle while the appropriate fasteners are still being sourced [1]. The Hyperion supply chain is much less complex, but still at the mercy of late deliveries. The central internal body frame structure was manufactured at Colorado and shipped to Germany where the fiberglass skin was manufactured. The fiberglass body was created at the University of Stuttgart, with very little margin to allow for time over-runs. If the production schedule is not met, it would be very difficult for the Hyperion team to meet their objectives of flight before school ends for summer break. This constraint highlights the problems faced by global industries that face delivery to customer deadlines.

Risk mitigation has been undertaken to ensure that failure to flight test does not come about. The German team began work on the negative molds, while Colorado, manufactured the internal structure of the plane, Figure 11. Due to the size of the molds necessary, the German team contracted an outside firm, Plandienst, to CNC-mill the molds of the centerbody, further requiring extensive planning and quality control, mirroring industry practices. While the molds were being constructed, students were allowed time to build the shipping crate necessary to ship the center body to Colorado for integration with wings and engine for flight testing. One critical requirement was also identified early in the project to ensure expedited shipping would be possible if need be. The largest shippable box dimension had to be kept under international priority freight classification, which is considerably more expensive.

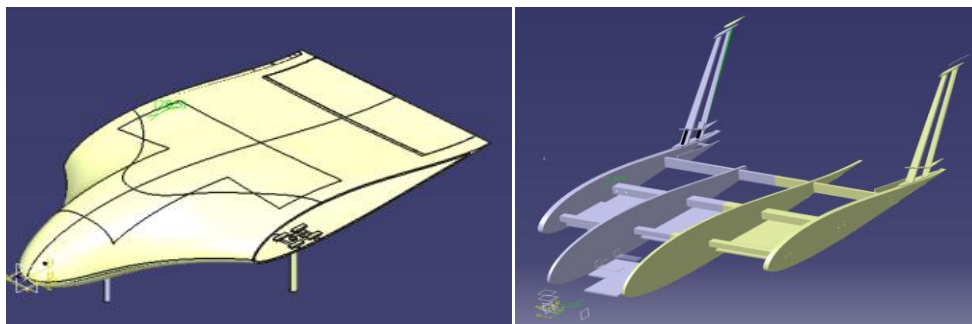


Figure 11. German Manufacturing Skin (Left) & CU Manufacturing Internal Structure (Right)

After the internal structure was shipped to Germany for integration with the outer shell, the Colorado team shifted their manufacturing efforts towards 4 ½ scale, fully functioning prototype planes and the full scale wings. By manufacturing the critical components first, time was managed effectively to maximize production and minimize down time. The ½ scale models were used to test flight control systems of the novel aircraft design.

To ensure that final assembly will be completed once the center body arrives from Stuttgart, a laser cut Interface Dimension Template (IDT) was designed to be used to verify the center-body produced in Germany will line-up with the wings produced in Colorado. One IDT was shipped to the Stuttgart team, while its exact twin remained with Colorado.

LESSONS LEARNED

Language and Cultural Barriers

Like the design and development of the 787, the Hyperion aircraft is a collaboration of multiple international teams. Although all of the German team members speak English fluently, and both the Australian and US teams are mostly made up of native English speakers, information is often lost due to subtle connotations of individual words or not conveyed effectively. This can partially be attributed to the dispersed evolution of the English language around the globe, which has led to unique expressions and different interpretations of the meaning of words in different cultures. It clearly shows how attention needs to be paid to the exact wording used when passing on information between the different geographically distributed teams. This is a good indication of the value of language skills in the current globalization of engineering in general and aerospace engineering in particular.

Early into the design phase, several weeks worth of progress were lost when weight and balance and elevator sizing problems forced the relocation of the propulsion system from a pusher to tractor configuration. This forced multiple sub-teams to adjust their work to compensate for the new design. Communicating the redesign across to all of the teams was ultimately not a problem. However, problems did arise with a general lack of understanding and communication amongst the international team deliverables and involvement in presentations. Including the international team members in presentations and design reviews was difficult and sometimes not possible due to the time differences and technological constraints of low budget video conferencing systems.

According to Tom McCarty, president of the local union representing Boeing engineers in Puget Sound, plane-making is best performed by a group of engineers and builders working in close proximity without the distraction of language barriers, cultural differences and bureaucracy [8]. Perhaps he is right; it would be easier if all team members were at the same location and there were no language barriers. By drawing on the talents of the world's engineers, international companies gain access to ideas and capabilities they would otherwise forgo. Likewise, Hyperion benefits from the knowledge and experience of its international colleagues. From an educational and experience point of view, nothing compares.

In order to incorporate the ideas and viewpoints of our delocalized team, regular conference calls have been held using Skype™ and Polycom™. This has enabled the three teams to give real-time updates and communicate issues that are difficult to articulate via email. By no means perfect, this system has been successful in coordinating the efforts of all teams. The students from all three schools never met personally until the final assembly and test flight at the end of the project in April 2011.

A related lesson is to understand and subsequently take advantage of the differences, rather than impose a common “comfortable” work knowledge and culture to the rest of the team. Achievements through teamwork are greatly enhanced when leadership understands the team members (groups) to take advantage of, and to complement skill sets. One of the hardest

lessons for any leadership to learn is to know when to “let go” and delegate. Having to deal with 3 universities with significantly different structures has certainly been an incredible journey in 2010/11. This paper is a mere introduction to many valuable lessons for this unique and pioneering global engineering design project. The students involved had a learning experience which should be highly valued in the aerospace industry.

Follow-the-Sun

A key component to the Hyperion project was the international work delegation and distribution. The underlying concept for each team to trade off work daily is conceptually ideal; however it is difficult in an academic environment. Each student team member has a unique schedule, due to variances in class schedules and part/full time employment. Being able to allocate even a single continuous 8-hour block to a Follow-the-Sun activity is unlikely for any student team. Therefore, Follow-the-Week (FTW) assignments became much more manageable and successful to implement. Rather than each person work 8-hour days, each person was given a specific design item to complete each week.

The largest benefit to FTW activities came in the form of the CAD design of the aircraft in which at the beginning of each week a set of part deliverables were assigned and then integrated with the model upon completion of the work week. As the designs matured and more parts became dependent on each other, fewer team members were needed to manage and continue the CAD designs, as the files become too large and complex for multiple people to manage. It was much more efficient to have 1-2 people leading the CAD designs in the later stages of development, rather than try and have 6-8 people trying to download and edit the master CATIA file simultaneously. Two advantages became apparent from shifting the design work from multiple CAD engineers at PDR to only a select few nearing CDR. First, the schedule risk was reduced, as development was extremely fast. The entire Hyperion aircraft was drawn in CATIA from scratch in little more than 4 weeks. The second advantage was it greatly reduced our integration risk. The primary CAD engineer at CU worked closely with the primary CAD engineer at Stuttgart, constantly in communication regarding the designs and manufacturing of the aircraft. After CDR and during manufacturing, both universities had a primary contact who was 100% up-to-date with the designs. This allowed for the rest of the team to quickly obtain the most current design information at any given time.

Part of the global learning objective is to go through project definition, with the added complexity of international schedules. The Follow-The-Sun concept for CDIO can be potentially taken to another level with a bit of lateral planning. In the beginning phases of the Hyperion project, there was time lost due to the immaturity of the project’s definition and a poor understanding of each universities class schedules, student work capabilities, and deliverables for the project. It appears inadequate to have only one student at one university (Colorado) develop a schedule complex enough to take full advantage of each school’s capabilities. A top-level project definition and work break down structure needs to be developed first, so that the first team can begin on their schedule. This is not to hinder the other students’ learning experience by not having to define requirements, as they have plenty of opportunities throughout the definition of the system architecture and subsystem requirements.

Ultimately, for the Sydney Team, the big challenge was allocating undergraduates to specific jobs over the summer break because the overall work schedules were not defined clearly and realistically enough by the project developers. Hence, Sydney “lost” most of the Year 1 student volunteers very early on and likewise lost many of the Year 3 students over their summer. Another option to consider is a three semester project in North-South hemisphere cooperation

with independent projects filling in the larger summer breaks in the North and South. There are “mechanisms” in place where students can choose to undertake a “project” unit of study, or independent study over summer which would help the continuity of the work.

Refinements to a global project course shall be made, just as processes are refined in industry. Academic advisors need to have a solid understanding of the different academic systems around the partner universities. The participating education programs may have different focus on technical fields and the desired learning outcomes may be different as well, as dependent on accreditation requirements. Students at the same official academic level at different universities may have different technical abilities and backgrounds and all need to be integrated in the skills profile of the global team. Academic planning needs to be significant.

International Shipping

The internal ribs and spars for the aircraft manufactured at Colorado were shipped to Germany where the external skin was manufactured and the central body assembled. The parts were declared as part of a remote control aircraft frame and so did not encounter American ITAR issues. Export documentation forms must be filed correctly by the sender and the recipient must fill out import documentation with correct content to allow adding value in Germany and shipping back to the sender. For the return shipment, the carrier’s pre-clearance team must have specific information on the bill of shipment. All these formalities are not in the mindset of most academics. Universities may not be well prepared to support international shipments correctly either. Academic and staff personnel and students who then have to handle the custom formalities do not have the appropriate education to handle import-export and mistakes are prone to be made. These mistakes may end in a quarantine of the shipment which can derail such a global project, especially because of the teaching time schedules. Customs have strict rules that need to be followed with highest precision and getting educated on that topic well ahead of shipment dates is adamant.

Financial Transactions

Financial transactions between universities may also be complicated by the fact that universities seldom or never exchange funds and thus have little experience in commercial transactions. The University of Colorado supported The University of Sydney, who did not received any primary funding for the project. This was feasible by setting The University of Sydney up as a vendor to the University of Colorado. As The University of Sydney is tax exempt, the transaction was not taxed and the deal was smooth. At the University of Stuttgart the accounting office was scared that they get taxed although the university is tax-exempt as well, and refused to be set up as a vendor to the University of Colorado. The University of Colorado is unable to freely distribute funds and must, by law, set up all partners as a vendor. This required creative ways to find a no exchange of funds process to reimburse the University of Stuttgart for the materials purchased for the project. The creativity lies in the payment of the four German students’ stay at the University of Colorado during the final assembly and testing of the aircraft.

CONCLUSION

The Hyperion project was intended as a design project for an aerodynamically efficient aircraft also using novel hybrid propulsion technology as a stretch goal. In addition the vehicle was designed to become a new test bed for future design improvements and further development of green aircraft technologies.

The international collaboration by teams from three international universities became a great learning experience. Students at different universities introduced new and unique skills that benefited the design concepts in all aspects. The totally new design concept was brought from an idea to a finished product in about 9 months. This is an extremely fast development of a novel and complex technology.

The lessons learned for engineering collaborations were substantial, but with a positive mindset of all international participants the operational procedures during the design phase and during the manufacturing phase were quickly absorbed by all the team members. A major bottleneck in the international manufacturing world is dealing with constraints by local governments and customs agencies, which remain a wild card in any international cooperation. Another major constraint is financial interaction between universities, which may be new territory for some departments.

Altogether, the Hyperion project was an exciting and rewarding experience for more than 30 students around the world. Hyperion is a first trial course which should be built upon and an improved assignment should be developed with the lessons learned for the next round of students.

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Biographical Information

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Eric Serani is a graduate student in Aerospace Engineering at the University of Colorado at Boulder and is getting his emphasis in vehicle systems and control. He was the lead systems engineer on the HELIOS Senior Design project that designed a hybrid-electric engine for use in RC aircraft. He continued with the hybrid technology and was a founding member of TIGON EnerTec, Inc. Outside of school you can find him flying or working on an experimental he and his father built while in high school.

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EXCURSIONS AND PARTICIPATION FROM COMPANIES IN A WEEKLY 5 ECTS COURSE

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ABSTRACT

A major factor when choosing the teaching methods in a new weekly 5 ECTS course was to enhance the student's engagement and responsibility for own learning by setting a frame enabling them to visualize themselves as civil engineers. The course is "Materials Durability and Repair" and it is offered to civil engineering students (both at bachelor and master level) as an advanced and elective course. A maximum number of students in the course is set to 25 for practical reasons. Excursions to relevant sites with structures suffering from decay or where repair actions take place was one important teaching method. The excursions took place preferably as introduction to a new part-topic so the students had a common knowledge platform from where the more theoretical teaching could set off. The teachers experienced higher motivation from the students when the excursions were before the lectures on the connected topic than vice versa, probably because the ability to relate the theory to the real life made the topic seem more relevant to them. At the excursions the students took samples which they analysed in the laboratory at the university to enhance the active learning. As these samples are from real sites, they also reflect the huge variability at such sites and sometimes the results did not support the theory. The frustration of not knowing all upfront places the student in a situation well known to working engineers and formed background for relevant discussions. Experts from companies took part in planning of some of the excursions and gave lectures on "real life cases" during the course. This involvement from companies introduced the students to the engineering community which they will join in the future. The companies engagement was important both to the training of scientific engineering skills and professional skills. Also important to the training of professional skills was the deliverables from the students, which was dissemination of own work in articles and a poster presentation performed in groups of 5 students. Student evaluations of the course were positive and currently the course is running for the third time. It is oversubscribed and has a waiting list, underlining the need for such a course.

KEYWORDS

Excursion, active learning, company participation, professional skills, problem based learning

INTRODUCTION

The overall learning vision when recently designing a new DTU course was to enable the students to identify themselves as civil engineers simultaneously to learning the required technical engineering skills. The aim is to foster a class of self-directed and reflective students who take responsibility for own learning as they can see a direct link from the taught topics to their future career.

The course connects the taught topics to the everyday life of many civil engineers and thus the course is supporting the CDIO education. Excursions and company involvement are powerful tools towards fulfilling the overall learning vision. The course aims at teaching the professional engineering skills (e.g. working in teams, communication in writing and orally) simultaneously to the technical skills. This is attained as suggested in [1] by implementing the professional skills as a matter of teaching and learning, rather than as an addition of new subjects in the existing curriculum (in this case technical curriculum).

The present paper reflects on the teaching methods used, including involvement from companies in relation to the overall learning vision.

About the course

The name of the course is “Materials durability and repair” (course 11569 at DTU). It is a 5 ECTS course and currently running for the third time. The course is offered to civil engineering students, both at bachelor and master level as a BSc/MSc- Advanced Course i.e. it is an elective course. It is compulsory for the students to have passed a basic course in materials science for civil engineers before enrolling. Foreign students have participated every time and the course is taught in English.

Material properties, decay and repair methods for three major groups of porous building materials - concrete, stones/bricks and wood - form the scientific and technical basis of the course. Each material is treated separately with the same emphasis. There are though also transverse topics and activities relevant to all three groups of materials linking the course topics together and increasing the general knowledge on durability of porous building materials. Depth of learning rather than the breadth of coverage is achieved by focusing on selected porous materials.

The general course objective given in the DTU course catalogue is “The participants will be able to determine damage mechanisms on construction materials in various situations and act upon the findings by suggesting an appropriate method for repair”.

The learning objectives of the course are developed in accordance to Bloom’s taxonomy [2] (which is the standard at DTU):

A student who has met the objectives of the course will be able to:

- Perform inspection on existing structures in relation to damage of materials
- Select and perform relevant laboratory analysis to support damage assessment
- Identify situations with risk for materials decay
- Debate damage mechanisms and transport routes
- Describe special repair issues when dealing with cultural heritage
- Select materials which are durable under given exposure
- Suggest and discuss methods for repair and maintenance

The first time the course was offered as a 3 weeks course during the summer 2009. There were 16 students. The course was then offered in the spring semesters 2010 and 2011 and taught once a week (4 hours) during the whole semester (13 weeks). Both times with the maximum numbers of students allowed (25), and both times about 40 students applied, but

the excess of 25 were declined participation. The maximum number of students is 25 due to the practical limitations of the laboratory equipment used.

TEACHING METHODS

Using the classification of the student's interest in the course from [3], there are probably few students in this elective course to whom the motivation lies within "(1) Only waiting to pass the subject". The first day of the course the students briefly present themselves orally to the class and this introduction includes the interest in the course (why enrolled?). It is probably not many students, who during this introduction would admit that they are only waiting to pass, but few students have told that one important reason was that the appointed time for the course fitted into a gap in their weekly timetable. These students may fall in group (1). The majority of the students are from the two groups "(2) A desire to accumulate useful knowledge for their future career, which students still see as a distant future, though one which exists for them" and "(3) An interest in looking more deeply into the specific knowledge of construction and building materials". The student are thus expected to be relatively well motivated when the course starts, and the teaching should continually seek to feed the motivation of both groups, i.e. at the same time stimulate the student's vision of themselves as civil engineers of the group (2) students and the scientific curiosity of group (3) students.

Making the students visualize themselves as civil engineers and act as such is a good background for the development of professional skills to become a natural part of the course. According to [1] teaching professional skills in engineering involves considerations about learning and development of competences among students. This includes how the choice of teaching methods create the context in which the engineering students learn and how the teaching design interrelates and facilitates the learning of professional skills. Throughout this course varied teaching methods are used to support learning of both technical skills and professional skills. The combination of teaching methods is made to support active learning in this semester course. In relation to each of the three groups of construction materials there are an excursion, lectures, and laboratory work. Each of these methods is discussed in the following in the context of the course.

Excursions

As the students generally lack personal experience in assessing damage in relation to building materials the learning process for each material was preferably set out with an excursion. These excursions went to an old concrete bridge, to a wooden roller coaster and a walk through the centre of Copenhagen, where the topic was salt damage of brick and natural stone. The students took samples for the experimental work at these excursions. Further a visit to The Danish Technological Institute (a self-owned and non-profit institution) was a part of the course in relation to wood decay and protection. All together these four excursions are a central part of the course.

As the build environment continuously changes and the repair of structures has a limited duration, the locations for the excursions changes from time to time. However, one excursion for each of the three main construction materials is planned. In the phase of planning the excursion, the network of the course teachers is utilized and different engineering companies as well as colleagues at the university are consulted in order to get an overview of relevant localities. At the excursions the students meets experts from outside the university, who introduce the students to the problems and solutions at the actual site. The experts are from different disciplines as engineers, architects, researchers and craftsmen.

The purposes of the excursions are multiple. They create a sense of community in the group and in relation to the learning of scientific and engineering principles the excursions are used

directly to form a common knowledge platform. They also enabled the students to relate to the topics taught theoretically in class to actual cases and thus give reflective students. The excursions are important in relation to having the students visualizing themselves as engineers working in a team with people of different professions.

Before the excursions, the students only had a very brief introduction to the topic. Few times it was impossible to have the excursion before the in-depth lecture from practical issues, so the order was changed. From the experiences with this, the students clearly seemed more motivated and active in discussions during the lectures in the cases where the excursions were first. However, in the course evaluation made by the students at the end of the course two students have suggested always to have the excursions finishing a topic and no students commented on the reverse order. From the teachers point of view it is easier to teach the topic in class when the excursions were first because the excursions had formed the common knowledge platform among the students in which the teaching could take a starting point.

After the excursions the students elaborated in groups on the most important new knowledge to remember in their future life as civil engineers and a common discussion in class on the topic followed.

Lectures and exercises

Traditional classroom lectures is another teaching methods in the course – though problem based learning is used. As stated above these in-depth lectures were preferably given after an excursion had opened the topic. After the excursions, the students visualize many of the topics taught. During the lectures the theoretical topics were related to the real life examples; either to findings from the excursion or through pictures of e.g. structures suffering from the actual type of decay or relevant repair actions. When available, material samples were used in the lectures. This line of giving the students a “feel” for the topic is in accordance to the suggested by [4]: “Probably the most effective strategy is to relate the new concept to an existing real-world problem.”

The classroom lectures were alternating with group work either as experimental work in the lab or written exercises, to engage the students and support their active learning.

Most of the classroom lectures were given by the two course teachers, but also other DTU experts and in few cases experts from engineering companies were involved in this teaching activity. This was to offer the students committed people with a high technical knowledge for every topic taught. The course teachers participated in the lectures given by others to be able to discuss with the students and relate to the lectures later in the course.

One lecture was dedicated to introduce the research topics of the two course teachers. The aim of this lecture was to illustrate to the students that new knowledge is continuously developed and that there are problems with building decay, to which there is actually no solution available. Some of the students may in their future career work together with researchers or visualize being a researcher themselves and this lecture gave them an insight into this professional life.

Laboratory work

Laboratory work was integrated in the course to support the students understanding of the theories learned during the lectures.

Samples for later analysis in the laboratory at DTU were taken at the excursions. These analyses were conducted in between the relevant lectures (same day). The students learn

both simple quantitative methods (which often can be used in the field), and complex qualitative methods. From these real samples the students from time to time went through the frustration of the analysis not supporting the predictions - a situation known from an engineer's life as well. Such frustration and the following re-thinking are rarely obtained using samples well known to the teacher as we tend to choose otherwise, i.e. samples clearly supporting the theory. The active learning from real samples stimulated relevant discussions.

INVOLVEMENT FROM COMPANIES

To support the overall learning vision – enabling the students to visualize themselves as civil engineers – the participation of people from companies plays a key role. The involvement of companies has also the positive effect that some of the expectations to the young people when they enter the civil engineering workforce become clearer to the students as well as the teachers, and this was used indirectly during the overall planning the course.

Engineering companies have been involved when finding sites for some of the excursions and one company also taught how to take core samples from concrete. This involvement ensures high practical relevance of the examples used and it increased the interest of the students. From a consulting company we obtained samples from a previous inspection of a concrete bridge together with anonymised reports. The students performed analysis and compared the results to the results in the report. Possible differences were discussed and the students saw a real-life report on the topic.

About two hours at the final part of the course is dedicated to “Repair Seminar”. Speakers from companies (4-5) were invited and they gave presentations on real cases, which relate to the topics taught during the course. By this the students were presented with cases similar to what they can be involved in during their later carrier and they meet the type of people they are going to work with. However, it is important to choose good speakers otherwise the students soon become impatient and loses concentration even if the topic was highly relevant. The overall topics covered during the Repair Seminar have been chosen by the course teachers and do not vary from time to time, but the speakers and thus the presentation of the topic does. This means that there are variations, but these variations reflect real life situations.

The experience from the involvement of companies was that they were very positive towards participating in the course. Everyone we contacted had a positive attitude towards our inquiry, but in a few cases the fact that the presentation had to be given in English made presenters exclude themselves. There were no payment for their effort, but many of the involved experts even thanked for the opportunity to disseminate their experiences to the students.

ASSESSMENT OF THE STUDENTS

The student worked in groups of five persons and the first two times the course was given the groups wrote four articles of four pages after a fixed template (from a scientific journal) and a short report. The first three articles focused on the hands-on-work with each of the three materials. For the final paper, the students made a more thorough investigation on a relevant site (chosen by themselves). In addition to the articles the students made a poster presentation, and this was followed by individual examinations. The workload of the students was too time-consuming compared to what can be expected of a 5 ECTS course and the third time the course was offered, the students made two articles, two individual quizzes and a poster presentation. The quizzes support the individual assessment.

Poster presentations and writing articles are two important communicative tools between engineers and thus the choice of these types of assignments underline the major learning vision of the course. The ability to professionally disseminate relevant engineering topics in a short and precise way to others in the engineering community is highly important. The poster presentation and the page limit of the articles forced the students to work actively on focusing and concentrating the message, which is also a useful competence in their future life. The oral presentation of own work in the class is in accordance to [5] where the use of laboratory work and sessions with student presentations was successfully used in a similar course on materials in civil engineering.

The choice of using article writing and poster presentations as assessment methods is a way to support the development of professional skills without significantly increasing the syllabus of the course, though short lectures on “How to write a scientific article” and “What is a good poster?” are given. The latter is supported by a discussion among the students where they evaluate some posters of the teachers. The course was closed with the students presenting their posters to each other.

If there is any single factor that supports good learning it is formative feedback [6] and thorough feedback was given to each group on the articles regarding both the scientific content and the form. For feedback to be effective students need to be clearly aware of what they are supposed to be learning and as they are unlikely to be perfect the first time, they need information as to where their deficiencies lie [6]. The points for improvements were made clear to the students while discussing the first article(s) and these points were expected improved in the final paper. The final paper and poster presentation account for 50% of the student assessment and thus it is shown that the first paper(s) are meant as a part of the learning process itself. The poster presentation is the last day of the course and this day the students also get feedback on their final article. Further an internal journal volume (for this actual course) with the articles from the class is distributed among the students.

The grades given were generally high and this may be seen as result of active learning giving in dedicated students.

STUDENTS COURSE EVALUATION

The course as evaluated by the students using the DTU standard evaluation forms. At present the third course is on-going and student evaluations are only available from the first two courses. Unfortunately the statistics regarding the number of students who have answered the forms are only 56% and 45%. All together 20 students have filled in the form for the two years. Due to this limited number of students, the evaluation may not be representative to all students, but the answers received are quite uniform.

The form has two parts. One is questions where the students evaluate the course on posed questions and the ratings are from 1 (strongly agree) to 5 (strongly disagree). Figure 1 summarizes the answers from the three most relevant questions in accordance to the topic of this paper.

Of the answering students, 60% strongly agreed that the teaching methods encouraged active participation which was one of the major teaching issues when designing the course. No students evaluated this point less than average and the goal seems fulfilled. Similarly it can be seen that the students found good continuity between the different teaching activities. There is an overall satisfaction among the students about the communication on their stand academically. One student disagreed and in the on-going course this point has been given priority.

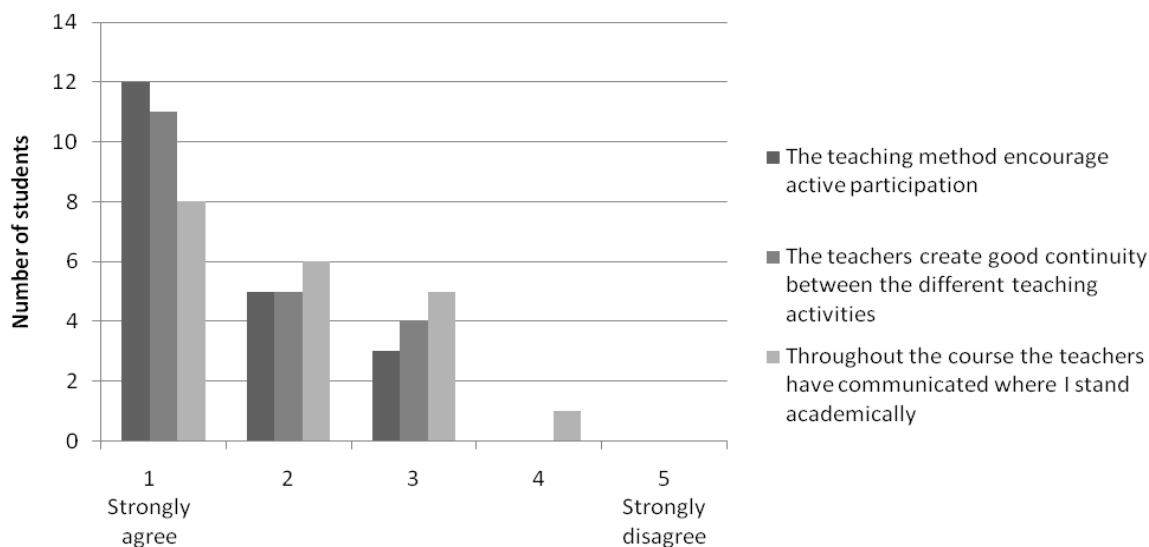


Figure 1: result from the course evaluation made by 20 students (50%).

In the qualitative part of the students evaluation 10 out of the 20 answering students stated that the excursions was a good idea and that they learned a lot from them. Some of the positive comments were:

- In this course, teachers integrate theory with practice, and applied theory to reality. This is a good way for us to learn knowledge.
- Very nice to have lectures/excursions/lab work and experiments. The reports were always fun to write because it was scientific “new” work done on the subject.
- Nice to see the materials in use at the excursions. All topics and articles were interesting.
- It has been nice to have the theoretical knowledge and the practical knowledge parallel. Good idea with trips to the real world.

These comments show that (at least) some of the students appreciated the effort laid on varying the teaching methods and on the variation between practice and theory.

The majority of the comments were positive. One student though complained that it was difficult to keep up with the course if you did not join all the lessons and excursions as some of the topics discussed were not to be found in the course material. This is a point which is difficult to address when having a course planned like this where you e.g. make experiments and discuss the findings, and discuss what you see at site at the excursions even though it was not central in the syllabus from the beginning of the course. Further using the participation of companies is also to loosen the grip on exactly what is taught and the weight of the topics, even though the overall topic always was discussed when arranging with the company. It is not possible to plan every detail on beforehand in the course when linking so much to companies and relevant real life examples as in this course.

PRACTICAL ISSUES IN PLANNING THE COURSE

It was necessary to limit the number of students to 25 (five groups of five persons) mainly due to the laboratory exercises. Highly specialized equipment was used as a Scanning Electron Microscope, where each group spend at least 1 hour with a technician studying their own samples, and other techniques were similarly time and labour consuming. Also the wish

to be able to vary (sometimes ad hoc) between lecture and laboratory work limits the number of students. Sampling at the excursions was also time-consuming at some of the localities (where drilling samples were taken) and a maximum of five groups were able to take samples within the scheduled time.

The continuity of the course is obtained by an initial in-depth formulation of the topics which must be taught. The topics are grouped and persons from industry, who can cover each area are identified. Neither of the activities is formulated so strict that the course is dependent on participation of specific experts. Planning of a course like this involving companies and with hands on experiences through excursion and lab work is time consuming to the teacher, in comparison to a traditional course with lectures followed by well described written exercises. However, this may be time well spend as it is awarding to work with dedicated students.

As the course has been both a three weeks course and a semester course, comparison is possible. It is easiest to plan as a three weeks course as the timing is not so strict to one afternoon a week, but the syllabus has been the same in both cases and there is no distinct difference in the student assessments and evaluations by the students.

CONCLUSION

Throughout the weekly taught 5 ECTS course “11569 Materials Durability and Repair” varied teaching methods are used to support learning of both technical and professional skills. The course supports the CDIO education in its design and teaching methods. Active learning was achieved through a combination of lectures, excursions, experimental work and involvement from companies.

Through excursions a common knowledge platform was formed from where the problem based teaching could set off. Companies were involved in different parts of the course to link the theory continuously to real-life situations. Some of the excursions were planned in cooperation with companies and some solely organized by companies. Further engineers from companies gave lectures on specific topics to consolidate the theory taught by the university lectures. The students were generally dedicated and good synergy between the students and the lectures (from university and companies) was obtained with benefit to all.

The student’s assessment of the course showed that they valued the use of varied teaching methods. Especially they appreciated the excursions and the alternation between theory and practice. The assessment also showed that the students agreed that the teaching methods encouraged their active participation in the course, which was one of the major goals when planning the course.

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A CONCEPT FOR A BACHELOR PROGRAM IN ELECTRICAL ENGINEERING

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ABSTRACT

The main concept for the Bachelor of Science in Engineering (BScE) in electrical engineering at Technical University of Denmark (DTU) will be described in this paper.

A new curriculum was introduced from the start of the autumn semester in 2010. The curriculum was the result of more than one year of work with first description of competences followed by a more detailed description of the single main areas. Finally, the new study plan was implemented through a number of courses satisfying some general rules for bachelor study plans.

KEYWORDS

Design of a new bachelor program, the design process, program implementation.

MOTIVATION

The previous program for Bachelor of Science in Engineering (BScE) in electrical engineering at Technical University of Denmark (DTU) was developed 10 years ago. It was the result of dividing the original master program at 5 years into a bachelor program and a new master program. This was a consequence of the Bologna agreement in EU.

The first bachelor program in was mainly based on existing courses in electrical engineering at DTU. Only necessary changes have been done to satisfy a general paradigm for bachelor programs at DTU.

Based on the experience from the start of the bachelor program in electrical engineering, it was time to consider a new program in 2009. The process was started in the summer 2009 with a 24 hours meeting where general concept for a new bachelor program was discussed. The work with the new program was completed the year after and was introduced for the students from the autumn semester in 2010.

The process of developing a new bachelor program will be described. Further, also the results of the process will be described and discussed.

THE PROCESS

The process of developing a new curriculum for a bachelor in electrical engineering at DTU will be described in details in the following. The process involved the following steps:

- A 24 hours starting up meeting – general discussing of the content of the new plan.
- Working groups looking into different subareas of the plan.
- A half day workshop discussing the results of the different working groups.
- The working groups complete their work based on the half day workshop.
- A draft to a new study plan is developed by the director for the study line in electrical engineering.
- The draft was presented for all interested, faculty members and students, in a two hour meeting.
- Suggestions and comments to the draft were received after the meeting.
- The draft version was updated based on the corrections, comments and suggestions.
- The new study plan was approved by the dean of education.

In the following, the single steps will be described. The main focus will be on the first steps, where the most interesting part of the process is.

The starting point

The area of the electrical technology at DTU is quite large and is divided between a numbers of different departments. As a consequence of this, it will not be possible for every group to get its own introduction course as a part of the new study plan. This problem needs to be handled by preparing a very detailed description of the content of the new study plan. This includes a specification of the competences that the students will get when they have completed the bachelor program in electrical engineering. This was the starting point for the work on the new study plan.

Another issue in connection with developing a new study plan is the fact that it needs to satisfy the general structure specified by DTU. This structure specifies that the students must have 36 course units (of 5 ETCS points) taken from four different groups. These groups are:

- Basic courses in math, physic etc. (take 9 out of 12 course units).
- General electro technological courses (take 9 out of 12 course units).
- Projects and general courses (9 course units).
- Optional courses (9 course units)

The 24 hours meeting

This meeting was central for the process to get the new study plan. All the basic elements were considered at this meeting. The participants were selected among the key persons in teaching from the related departments in the education. Also some key persons from the administration participated in the meeting.

The first point was the competence description for the study plan. The existing competence description was discussed followed by an update of these. This work was done as group work. The new set of competences includes both electro technological competences as well

as more general competences. Moreover, the students following the bachelor program will get the competence to continue the study at a master program in electrical engineering or a related program.

Based on a new set of competences for the study program, all participants developed a number of course descriptions (title, suggested semester, content) they found relevant for the new study plan. Based on these large number of course descriptions, a new group work is done. This time, the work has focus on creating a structure for the central (mandatory) part of the study plan based on these course descriptions. The result of this work was an identification of the central parts for a new study plan.

A number of central elements were identified. These elements were subjects for further investigation after the meeting. This work should end up in a detailed description of the content of the specific part, including which elements should be mandatory and which elements should be optional.

The working groups

The working groups were organized by a chairman selected among the participants from the first meeting. The other members of the groups are selected by the chairman to get representative groups. The different groups are the following:

- Analogous electro technology
- Digital electro technology
- Signal analysis
- Electromagnetism
- Project work
- Programming
- Optional study lines
- External co-operations

The result of this work was presented at half day workshop two months after the first 24 hours meeting.

The half day workshop

The results of the different groups were presented at this workshop. Everyone were invited to join this workshop, it was not restricted to the participants from the 24 hours meeting.

The results were shortly presented following by a discussion. The outcome of this workshop is a common agreement of which elements should be mandatory and which should be optional in the different subjects.

Special the works of two groups were interesting. The groups dealing with project work and optional study lines are central in the work of creating a study plan with connection. The students will have the first project work at first semester and again a larger project work at fourth semester. The project work at first semester should among other things be used to introduce the different directions/areas in electro technology. Further, the project work should also give the students a connection between the different courses at first semester, so they will be able to see the relevance of these courses. At last, it should also give the students competences in elementary lab work.

In the last part of the bachelor program, the students can select a number of courses freely among all courses at DTU. To give the students some guidelines for the selection of these courses, a number of optional study lines have been suggested. These suggested study lines goes into different directions in the area of electro technology. It is not the intension that the students should be specialist in a specific area through a given study line. A study line will give the student courses at the level over the mandatory courses in the area. Further, it will also prepare the student for the selection of a master program after the bachelor study.

As a result of the half day workshop, a number of the groups continue their work based on the many suggestions and comments from the other groups.

A new study plan

Based on the above work, a draft for a new study plan was derived by the director for the Bachelor of Science in Engineering (BScE) in electrical engineering. The new study plan was based on the set of competences specified at the first 24 hours meeting. Together with the other results from this meeting together with the detailed results from the seven working groups, a new plan was derived. The study plan was a compromise between a large number of suggestions and possibilities.

The draft version of the study plan was send to all involved departments and all bachelor students. Further, the plan was presented at a two hour meeting for all interested people. As a result of this meeting, a number of comments and suggestions appear. A minor modification of the plan was derived based on these comments and suggestions from this meeting. This new study plan was then approved by the administration at DTU.

THE RESULT

The result of the work was a new study plan for the BScE in electrical engineering. The new study plan is based on the following set of competences:

- Has an understanding for the electro technology area
- Be able to analyse analogous circuits and network with respect to both signals and effect purpose.
- Understand the principle behind digital system construction and digital circuits and be able to construct connected digital systems.
- Understand the principles for handling of signals in continuous-time and discrete-time, can analysis system functions and handle stochastic signals.
- Understand the general electromagnetic principles.
- Can analyse larger problems and come up with solutions on subsystems level.
- Can estimate if subsystems shall be realized in hardware or software.
- Can applied electro technology principles on at least one of the following areas: energy, sound and acoustic, wireless systems, embedded systems and programming, electronic and electromagnetic systems, automation and instrumentation in the final bachelor project.
- Is independent and can reflect over problems inside the electro technology area.
- Have competences in English to be able to understand teaching in English at master level courses.
- Have competences to be able to continue the study at master level in area of electro technology after the bachelor degree.

The study plan consists of a list of mandatory courses in:

- Basic courses in math, physic etc.
- General electro technology courses.
- Projects and general courses.

At first semester the course “Engineering practices – Electro technology” (two course unit) is the first course where the electro technology area is introduced. In the first part of the course, the different study lines are introduced through a number of small projects. These projects are related to the different optional study lines. A joint project is given in the last part of the course. This focus in this part is to give the students a connection between the different courses at first semester. The project will also give the student an introduction to laboratory work. They should all be able to work in an electro laboratory and be able to handle all the standard electro instruments.

At fourth semester, the course “Introductory project – Electro technology” (two course unit) is a follow up at the first project course. The main focus in this course is the project work. The students should be able to work systematic with projects. Further, the course will also connect the other courses in the study plan. It is the intension that as many as possible of the projects are in the area of “Green Combat” at DTU. This is a second yearly event at DTU where the focus is in the area of green technology.

The last part of the study plan consists of 6 optional study lines. These study lines are selected such that all major areas are included in at least one study line. These lines will give the students an overview of the different major directions that it is possible to follow both as bachelor student as well as in a following master student. Some of the suggested study lines are tin entrance to other master lines than in electrical engineering. The 6 optional study lines are:

- Energy
- Sound and acoustic
- Wireless systems
- Embedded systems and programming
- Electronic and electromagnetic systems
- Automation and instrumentation

All 6 study lines consist of a short description of the area together with two central key courses. These two courses will give a good introduction to the area. Based on these introduction courses, it is the intension that the student should be able to select other courses in relation to the area.

By including only two courses in each study line will give the student the possibility to select more than one study line. This is to avoid that the bachelor students gets specialists in a certain area. The specialization is taken place in the master programs.

To get in close contact both with teachers and students, some teams has been established. A semester team is set up for every semester including the teachers for the single semesters. It is here possible to coordinate and discuss the teaching and the single courses at every semester. This is important to get an optimal coordination of the different courses at the single semesters. In parallel with this, a student team is also established for every year. It is here possible to get in close contact with the students, get information and suggestions from them. Through a good contact with the student team, it is also possible to take care of problems before it gets into major problems.

At last, it is also the intension in the study plan that there should be a (small) number of subject teams related to different areas. The intension with these teams is that they should

take care of the coordination of a certain subject between the different semesters. This has not been established yet.

CLOSING REMARKS

The result of the work over a year is a new bachelor study plan. It has been possible to involve a large number of people to take part of this work. As a consequence of this, the ownership of the plan is shared by many people at the involved departments.

In spite of everyone is not agree with the final study plan, everyone has been able to take part in the work with the new plan and in that way have influence on the final plan. In that way, the necessary compromises have also been more clearly for everyone.

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Dr. Henrik Niemann is connected to the Automation and Control group at the Department of Electrical Engineering. His current research focuses on robust control, fault diagnosis and fault tolerant control. Applications include energy systems, process systems, mobile systems, cooling systems etc.

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INTEGRATION OF A COMPUTATIONAL MATHEMATICS EDUCATION IN THE MECHANICAL ENGINEERING CURRICULUM

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ABSTRACT

The rapid development of computers and the internet has given new opportunities for engineering work as well as for teaching and learning. The use of advanced modern mathematics is becoming increasingly more popular in the engineering community and most problem solutions and developments incorporate high precision digital models, numerical analyses and simulations. However, this kind of mathematics has not been fully implemented into current engineering education programs. Students spend too much time solving oversimplified problems that can be expressed analytically and with solutions that are already known in advance. Instead, we should be using computers to solve more general, real-world problems. Here we present the integration of a computationally oriented mathematics education into the CDIO-based MSc program in mechanical engineering at Chalmers. We have found that the CDIO-approach is beneficial when designing a reformed mathematics education and integrating the mathematics in the curriculum. In the reform of the mathematics education, traditional symbolic mathematics is integrated with numerical calculations and the computer is used as a tool. Furthermore, the computer exercises and homework assignments are taken from applications of mechanical engineering and solutions are analyzed and discussed by means of simulations. The experience is very positive. The students' interest in computation and simulation has increased. The students consider the computer an important tool for learning and understanding of mathematics. Students spend more time training mathematics and solve more problems.

KEYWORDS

Engineering mathematics, Integrated, computational oriented mathematics education, Full view of problem solving, Virtual learning environments

INTRODUCTION

The development of computers, hardware and software, has led to new possibilities for engineering work in which mathematically complex problems solved in the computer, visualization and simulation play a central role. The development has also led to better conditions for teaching as well as learning of mathematics and other engineering disciplines. It is possible to solve not only special, simplified problems but also complex realistic problems and to visualize solutions, phenomena and theoretical aspects. Visualization can be used to facilitate understanding and learning and promote interest in mathematics. In general, the basic courses and textbooks in mathematics do not take advantage of this development.

The CDIO model for engineering education stresses engineering fundamentals set in the context of Conceiving – Designing– Implementing – Operating real-world systems and products. Further, the model emphasizes a holistic view on problem solving and the ability to translate skills into practice [1]. This has in particular affected the design courses, project courses and more applied courses. Today facilities suitable to build physical models and prototypes exist in many engineering programs. An important part of problem solving chain is simulations and the need for a virtual prototype lab (that is, an engineering tool for calculation and simulation) is obvious. The introduction of this requires a more computation and simulation oriented mathematics education. Furthermore, we are convinced that the computational aspects, construction of numerical algorithms and programming of mathematics should be included from the beginning in all mathematics courses. This makes it possible to study more realistic problems and to use simulations, which promotes understanding and motivates the study of mathematics.

In the academic year 2007–2008 a reformed mathematics education for the Master of Science in program in Mechanical Engineering at Chalmers was launched.

MATHEMATICS IN CDIO

Before we elaborate on our approach to teaching mathematics, it is appropriate to review the mathematics-related elements of the CDIO framework – the syllabus and the standards.

What mathematics should be taught in a CDIO program? On one level, this is a question that is not considered in the CDIO syllabus. Mathematics primarily belongs to the discipline-dependent section 1 – Disciplinary knowledge and reasoning. Indeed, mathematics is discipline-dependent and programs in mechanical engineering and computer engineering, for example, emphasize different mathematical topics. However, also the sections 2–4 of the CDIO syllabus [2] include mathematical topics. CDIO skills topics with a strong foundation in mathematics include 2.1.2 Modeling, 2.3.4 Trade-offs, Judgment and Balance in Resolution, and 4.4.4 Disciplinary Design. Broadly speaking, it can be argued that the mathematics in a CDIO program should, in the context of the specific discipline of the program, emphasize modeling, decision-making and design.

How should mathematics be taught in a CDIO program? Again considering the CDIO framework, we observe that several CDIO standards [3] are relevant for the mathematics curriculum in a program, and propose strategies for designing the mathematics teaching, learning and assessment in the program. Standard 6 – Engineering workspaces – suggests that a CDIO program should be supported by student workspaces that supports hands-on, concrete learning of product realization. Most published examples of CDIO workspaces (e.g., [4]) has described physical prototyping workspaces. However, it is equally important that a CDIO program is supported by a virtual learning environment designed with the same underlying principles in mind including interactivity, use of

state-of-the-art modeling and simulation tools, and computer-based experimentation and assessment. In a CDIO program, the mathematics curriculum is enriched with experiential, industry-related tasks: students solve real problems using computer tools ([5]). Standards 7 and 8 – Integrated and active learning experiences – interpreted in the perspective of mathematic – point to the need to integrate mathematics learning with other disciplines and to adapt active learning techniques in the mathematics curriculum. The benefit of integrating mathematics education with computational-intensive disciplines such as strength of materials might be evident but there is also potential in integrating mathematics and the training of communication skills, see [7]. Such an approach will bring the mathematics learning closer to learning in design-oriented courses, strengthen student motivation and attainment [9].

In conclusion, a CDIO program should include a mathematics curriculum where

- Modeling and decision-making are brought forward in the context of the mathematics underlying the specific discipline of the program.
- Mathematics teaching and learning is integrated with disciplinary courses.
- Active learning techniques such as simulations and parameter studies are emphasized.
- An interactive virtual mathematics learning environment which supports teaching, learning and assessment.

In the paper, we will return to these basic characteristics and explain and exemplify how they are addressed in our program, the mechanical engineering program at Chalmers University of Technology.

THE MECHANICAL ENGINEERING PROGRAM AT CHALMERS

The Master of Science in Mechanical Engineering program is a five year program divided into two cycles in accordance with the Bologna structure. The first cycle consists of three years of full time studies and corresponds to 180 ECTS and ends with the degree of Bachelor of Science. The second cycle is a two year's (120 ECTS) master program. After completing both cycles the student is awarded the Swedish degree "Civilingenjör" as well as the degree of Master of Science.

In 2000 the Mechanical Engineering program at Chalmers University of Technology teamed up with programs from The Royal Institute of Technology (KTH), Linköping University and Massachusetts Institute of Technology to form the Wallenberg CDIO project, which later become the CDIO Initiative. This was the starting point for an education development process with focus on engineering as a profession that involved many changes including a framework for curriculum design, the integration of general skills, pedagogic and learning environment innovations [8]. Recent developments using CDIO-model at the Mechanical engineering program at Chalmers are the integrated computational mathematics education and sustainability.

The program has organized the education and curriculum focusing on the engineer's professional role, the integration of non-technical skills and contexts. The base of the program is the fundamentals of mathematics and mechanical engineering with emphasis on common principles. This by having joint projects and assignments between mathematics and the basic courses in mechanics and strength of materials. These projects include the full view of problem solving, from selecting a model and setting up equations, describing the model to solve equations and simulate and to assess quality of the choice of model and the accuracy of the solution. The purpose of working with the full view, joint projects and the sequence of courses is that education and learning of a topic shall not be isolated in a specific course. Applications from the Fundamental topics are introduced early in the

learning plan to prepare for the design-implement-(design-build) projects where real and relevant products and systems are to be created. There are at least one project in each grade.

The basis for program development and program monitoring is the CDIO-based program description with which decompose in course objectives through a program design matrix. The program description can be found at the Program website [6]. Design and integration of the mathematics education are based on program level goals and in which courses they are fulfilled are displayed in the program design matrix. Below we cite the program goals related to mathematics

The Master of Science in Mechanical Engineering graduate shall

- 1 Be able to put into practice (apply) mathematics and fundamental science within applied mechanics and have an insight into basic principles of classical physics with focus on
 - 1.1 being able to solve linear and nonlinear systems of algebraic equations by numerical methods,
 - 1.2 being able to solve ordinary differential equations of the following types; separable, inhomogeneous with constant coefficients and Euler's,
 - 1.3 being able to solve by numerical methods linear and nonlinear ordinary differential equations inclusive reformulating to a first order system,
 - 1.4 being able to solve the eigenvalue problem for continuous and discretized systems
 - 1.5 being able to use the Finite element method to solve partial differential equations,
 - 1.10 based on given models and mathematical formulas, being able to program solutions, including graphic presentations of engineering problems in Matlab.
- 4 Be able to formulate theoretical models and set up equations to describe the models. Solve equations in order to simulate reality and assess the reasonableness of the choice of model along and the solution's level of accuracy.
- 5 Be able to analyze, solve and simulate advanced mechanical engineering problems within the selected specialization area/master's program by using modern, computer-based tools and from these, selecting the most appropriate ones

The reformed courses in mathematics have been developed to meet these goals. Cornerstones in the reformed mathematics education are

- To highlight and clarify modeling, computations and simulations.
- Full integration of computational aspects (including programming) and symbolic aspects of mathematics,
- Emphasis on the full view of problem solving, *i.e.*, set up the mathematical model, formulate the equations, solve the equations and visualize the solution to assess the correctness of the model and the solution,
- Computer exercises where students solve problems including visualization by developing their own codes in Matlab.
- The finite element method, which is taught and used already in the first year courses in mathematics and mechanics.
- Assignments, exercises and applications are taken from the parallel courses in mechanics and strength of materials, and other fundamental mechanical engineering courses. Technical relevant problems are solved.

- Close cooperation with courses in mechanics and strength of materials, including joint project work, computer exercises and assignments.
- Teaching and learning of mathematics in applied courses such as mechanics, strength of materials and control theory.
- Teaching and learning of mechanics and physics in mathematics courses.

In the work of the reformed mathematics education, we have specifically developed:

- A basic course in programming in Matlab.
- Compendium and lecture notes in computational mathematics.
- Computer-oriented exercises, assignments and team projects that are used simultaneously in the mathematics courses and in courses of mechanics and solid mechanics.
- Interactive learning environments in mathematics and supported the development of a Virtual learning environment in the statistics courses

The new mathematics education covers all the mathematics courses in the first year and the mathematical statistics course in the third year. Mathematics courses and simultaneously taught courses are listed below (the academic year is divided into four study periods of eight weeks).

Year 1

- Study period 1. *Introductory course in mathematics* (7.5 ECTS), *Programming in Matlab* (4.5 ECTS) and *Introduction to mechanical engineering* (continued in Study period 2).
- Study period 2. *Calculus in a single variable* (7.5 ECTS), *Computer aided design* (4.5 ECTS) and *Introduction to mechanical engineering* (7.5 ECTS).
- Study period 3. *Linear algebra* (7.5 ECTS) and *Statics & strength of materials* (7.5 ECTS).
- Study period 4. *Calculus in several variables* (7.5 ECTS) and *Strength of materials* (7.5 ECTS).

Year 3

- Study period 4. *Mathematical statistics* (7.5 ECTS) and *Bachelor's thesis project* (15 ECTS, launched in Study period 3).

Year 3 also includes the elective course *Transforms and differential equations*. This course is not included in the new mathematics education and is therefore not discussed here. Further, year 3 also includes the elective course *The finite element method*. This course is a continuation of the courses *Calculus in several variables* and *Strength of materials* and uses in a natural manner the same pedagogics.

Numerical calculations, Matlab programming and simulations are included in most of the applied courses in years 2 and 3, for example, *Machine design*, *Mechatronics*, *Thermodynamics & energy technology*, *Integrated design and manufacturing*, *Materials and manufacturing engineering*, *Fluid mechanics*, *Control engineering*, *Heat transfer*, etc. The final two years, the specialization, is made in a masters program. Numerical calculations, Matlab programming and simulations are also included in most masters programs.

THE REFORMED MATHEMATICS EDUCATION

The main idea of the reformed mathematics education is a complete integration of computation (numerical analysis) and analytical (symbolic) mathematics. This requires computers and a programming environment. We chose Matlab because it is a suitable environment, it is easy to use, there are many built-in functions and "Tool Boxes"(packages) for applications, and Matlab is used both in subsequent courses and in research at departments and companies linked to the Mechanical Engineering program. It is also relatively easy to create graphs, simulations and animations in Matlab.

Matlab is used by students for calculations and illustrations of mathematical concepts and phenomena using advanced built-in functions and packages. Students write their own program for implementation of numerical algorithms for solving technical problems from applications and to present results. We think it is very important that the students write their own programs. This provides them with programming skills and knowledge, and it increases their understanding of mathematics and algorithm construction. Finally, it gives students the confidence to solve all kind of problems, provide training in abstract and logical thinking and problem-solving, which is very valuable in future courses and the working life.

The use of computing in mathematics courses increases the motivation for the study of difficult mathematical concepts. When we generate approximative sequences with the bisection method it becomes necessary and meaningful to study the convergence of sequences and we can carry out proof of the Intermediate Value Theorem. Integral theorems of multivariable analysis may in a traditionally structured course only be used to rewrite difficult integrals, which the students (and the professor) probably consider to be pretty useless. We can now justify the Gauss divergence theorem by deriving the heat equation with mixed boundary conditions (as well as pointing out the similarity with boundary value problems of elasticity theory) and to derive the finite element method. Our approach was inspired by [10] and first developed in the Chemical Engineering Program at Chalmers [11, 12]. For further discussion, see [13].

The course literature consists of two traditional mathematics textbooks, [14], [15], supplemented with a compendium of Computational Mathematics and computer exercises, etc. In the "Mathematical statistics" course the literature is linked as PDF-documents in the Virtual Learning Environment.

Teaching consists of lectures (2–6 hours/week); exercises (0–4 hours/week), computer exercises (2–4 hours/week) and project team work. The examination is mainly in the form of a written final exam that may be located in a computer lab together with quizzes, computer exercises, and project reports on a scale that varies between the courses.

The following is a short description of the courses with emphasis on the computational topics.

INTRODUCTORY COURSE IN MATHEMATICS

The course covers functions of one variable, continuity and derivative. Vector geometry and the Gauss elimination method for linear systems of equations are also included.

We put a special emphasis on the proof of the intermediate value theorem via the bisection algorithm, which allows us to introduce concepts like Lipschitz condition, convergent sequence, decimal expansion (= real number) in a computational context.

Computer exercises:

1. *Function gallery.* To plot the graphs of a large number of functions that are important to know.

2. *Geometry.* To write Matlab functions for the scalar product, orthogonal projection, cross product and so on.
3. *The bisection algorithm.* To implement the bisection algorithm in order to deepen the understanding of the intermediate value theorem, convergent sequence, and decimal expansion. The program solves equations of the form $f(x) = 0$ with arbitrary function f .
4. *Fixed point iteration.* To write a Matlab function based on the the fixed point theorem for contraction mappings. This solves equations of the form $x = g(x)$.
5. *Numerical derivative.* To write a Matlab function for approximative computation of the derivative of an arbitrary function.
6. *Newton's method.* To write a Matlab function for Newton's method with numerical computation of the derivative. This solves equations of the form $f(x) = 0$. This is repeated in study period 2 and 4 in more general contexts.

MATHEMATICAL ANALYSIS IN ONE VARIABLE

We continue the study of functions of one variable and the computational topics include computation of the integral and solution of differential equations.

In the computer exercises we write our own Matlab functions for the following:

1. ODE1: primitive function.
2. ODE2: Euler's method for systems of ODE (initial value problems).
3. ODE3: implicit methods for systems av ODE (initial value problems).
4. ODE4: a boundary value problem (a shooting method combining a solver for initial value problems with with the Newton solver from the previous course). The program is used to solve a heat conduction problem.

LINEAR ALGEBRA

This is a rather traditional course in linear algebra but with computer exercises from the simultaneously taught course *Statics and strength of materials*:

1. *Matrix algebra.* Analysis of a statically determined large plane truss. In the course "Statics and strength of materials" the truss is made indeterminate and the truss is analyzed by the displacement based matrix method. This also serves as an introduction to the finite element method.
2. *Geometry.*
3. *Error analysis* for the solution of linear systems of equations based on the condition number of a matrix.
4. *The least squares method.* Calibration of Norton's law for creep of copper at elevated temperature.

CALCULUS IN SEVERAL VARIABLES

In addition to the traditional topics of multivariable calculus, we introduce *boundary value problems* for partial differential equations and *the finite element method*. We begin with boundary value problems in one variable of the general form:

$$\begin{aligned} -D(a(x)Du(x)) + c(x)u(x) &= f(x) && \text{for } x \in I = (K, L), \\ a(x)D_n u(x) + k(x)(u(x) - u_A) &= g(x) && \text{for } x = K, x = L, \end{aligned}$$

and we derive the finite element method in one variable. The derivation is based on the fundamental theorem of calculus and integration by parts. After this we can do the same thing in several variables:

$$\begin{cases} -\nabla \cdot (a\nabla u) + cu = f & \text{in } D, \\ \hat{\mathbf{N}} \cdot (a\nabla u) + k(u - u_A) = g & \text{on } S_2 \text{ (Robin boundary condition),} \\ u = u_A & \text{on } S_1 \text{ (Dirichlet boundary condition).} \end{cases}$$

Here we use the Gauss divergence theorem (a multivariable version of the fundamental theorem of calculus) and the integration by parts formula

$$\iiint_D \nabla \cdot \mathbf{F}\phi \, dV = \iint_S \hat{\mathbf{N}} \cdot \mathbf{F}\phi \, dS - \iiint_D \mathbf{F} \cdot \nabla\phi \, dV.$$

The boundary value problems are interpreted in terms of heat conduction, but the analogy with the equations of strength of materials is also displayed. We also think that it is important to derive and understand the meaning of the boundary conditions in this general form so that the students will be able to use professional finite element programs where all these terms are present.

Computer exercises:

1. *Visualization* of multivariable functions.
2. *Jacobi and Newton*. The students implement Newton's method for systems of nonlinear equations with numerical computation of the Jacobi matrix.
3. *Extreme value problems*. Critical points are computed by means of the Newton solver from the previous exercise.
4. *The finite element method in 1-D*. We use a Matlab program for boundary value problems in one variable with the same datastructures as the "PDE Toolbox" as a preparation for the following exercise.
5. *The finite element method in 2-D*. We use the "PDE Toolbox" of Matlab.

MATHEMATICAL STATISTICS

The course covers basic probability theory and statistics with emphasis on concepts and computational methods of importance for mechanical engineering applications. The course also introduces elements of experimental design. The course is built-up by lectures and web-based exercises with the use of a Virtual Learning Environment (VLE) aided with statistical routines of Matlab. The virtual learning environment includes about 700 numerical examples and a compulsory team project. The team project considers prediction of probability for crack growth and failure of a railway structure (the Iron Ore-line between Kiruna and Luleå in the north of Sweden). The input data are the contact forces between rail and wheel and the temperature measured in the field. The project includes a report that is assessed by the teachers.

EXAMPLES OF PROJECT WORK AND COMPUTER ASSIGNMENTS

COMPUTER ASSIGNMENT 4 — FINITE ELEMENT METHOD IN 1D

From the course *Calculus in Several Variables* we the following assignemnts.

GOALS

To learn how to solve boundary value problems in one variable by the finite element method in Matlab. This is also a preparation for the “PDE Toolbox” for finite elements in two variables.

LITERATURE

[FEM1](#).

Matlab programs

[MyPoissonSolver.m](#). [BdryData1.m](#). [EqData1.m](#).

Copy the files by clicking on the links. Type `help MyPoissonSolver` on the command line and read the documentation.

INTRODUCTION

The program `MyPoissonSolver` solves boundary value problems of the form

$$\begin{aligned} -D(a(x)Du(x)) + d(x)Du(x) + c(x)u(x) &= f(x), & \text{for } x \in I = (K, L), \\ a(x)D_n u(x) + k(x)(u(x) - u_A) &= g(x), & \text{for } x = K, x = L. \end{aligned}$$

Here $D = \frac{d}{dx}$ and D_n is the directional derivative in the outward direction, i.e., $D_n = -\frac{d}{dx}$ at $x = K$ and $D_n = \frac{d}{dx}$ at $x = L$. The program is based on the finite element method with piecewise linear functions.

The function `MyPoissonSolver` with the declaration

```
function [U, A, b] = MyPoissonSolver(p, t, e, EqData, BdryData)
```

assembles and solves the system of equations $AU = b$, where A is the the stiffness matrix, b is the load vector, and the vector U contains the node values $U_i = U(x_i)$ to the finite element solution $U(x) = \sum_{i=1}^n U_i \phi_i(x)$.

Information about the computational mesh is stored in the matrices `p, t, e` with the same structure as in Matlab’s “PDE Toolbox” that we will use later (also in the mechanics course). The data of the problem, a, d, c, f, u_A, g , are defined in the function files `EqData.m` and `BdryData.m`.

The matrix p. The coordinates of the nodes

$$K = x_1 < x_2 < \cdots < x_{i-1} < x_i < \cdots < x_{n-1} < x_n = L$$

are stored in the vector `p` of type $1 \times n$.

The matrix t of type $3 \times (n - 1)$ contains information about the $n - 1$ intervals

$$I_i = (x_i, x_{i+1}), \quad i = 1, \dots, n - 1.$$

More precisely, column number i contains indices (pointers) pointing to the endpoints of interval number i , that is,

$$\begin{bmatrix} i \\ i + 1 \\ 1 \end{bmatrix}$$

The third digit is a tag ("subdomain reference tag"), which I have set to 1 here, and which can be used to mark which subdomain the interval I_i belongs to, if you have divided the interval $I = (K, L)$ into subdomains. This could be practical if the coefficients are given by different expressions in different parts of I .

The matrix e contains information about the boundary points,

$$e = \begin{bmatrix} 1 & n \\ 1 & 2 \end{bmatrix}.$$

Here the first row contains pointers to the two boundary points, here x_1 och x_n . The second row contains tags ("reference tags") marking which boundary point it is, here 1 is the left endpoint and 2 the right endpoint. Since we use pointers it does not matter in which order they are entered. The following matrix gives the same result:

$$e = \begin{bmatrix} n & 1 \\ 2 & 1 \end{bmatrix}.$$

The same is true for the matrix t .

This may seem unnecessarily complicated but it is a preparation for the "PDE Toolbox", where this structure is needed to describe a mesh of triangles in the plane. In two dimension there is no natural way to number the points, triangles, and boundary points, so we need to use pointers. In the "PDE Toolbox" p, t, e means "points", "triangles", "edges".

PROBLEMS

PROBLEM 1. PIECEWISE LINEAR FUNCTION.

Create a mesh in the interval $I = (0, 1)$ with only $n = 9$ points (so that you can clearly see all of them):

```
>> n=9
>> p=linspace(0,1,n)
>> t=[1:n-1; 2:n; ones(1,n-1)]
>> e=[1 n; 1 2]
```

Create and plot a piecewise linear function:

```
>> V=sin(7*p)
>> plot(p,V,'.-')
```

(See Figure 3 in FEM1.)

PROBLEM 2. MYPOISSONSOLVER

Run the program with the same mesh and the given function files EqData1.m and BdryData1.m. Read the documentation (`help MyPoissonSolver`) and the files to see what boundary problem it is. (It is one of Problem 1.1–1.5 in FEM1.)

```
>> [U, A, b] = MyPoissonSolver(p, t, e, @EqData1, @BdryData1);
```

Look at the stiffness matrix A and see that it is tri-diagonal.

Plot the approximate solution U and the exact solution u in the same figure.

Refine the mesh to $n = 101$ points and compute again.

FURTHER PROBLEMS

The remaining problems cover heat conduction in an inhomogeneous material, traction of a bar, elasticity in rotational symmetry.

PROJECT WORK 2 — STRESS INTENSITY FACTOR COMPUTED WITH FEM

This project is from the course *Strength of materials*.

The project considers a two dimensional stress analysis of a thin plate with three holes subjected to uniform stress at the vertical boundaries, see Figure 1. Plane stress conditions are assumed. `beginfigure[hhh]`

The analysis is carried using the finite element method and the PDE-toolbox in Matlab. The task is to calculate the stress concentration factor K_t which is defined as

$$K_t = \sigma_{\max} / \sigma_{\text{nom}}$$

By varying the distance b in the figure, the students should be able to decide whether the stress concentrations near the holes are correlated or not. Further, the calculated K_t should be compared with tabulated values from handbooks. To reduce the number of elements, symmetries should be used and only a quarter of the plate needs to be considered. This means that special attention needs to be put on the boundary conditions. There are several aims with this assignment, for example: (1) By visualizing the stress distribution, the students can develop an intuition about stress distributions and how the stress is increased due to abrupt changes in geometry. (2) Motivate the need to study the governing equations of elasticity. (3) It serves as an introduction to the finite element method. (4) It provides an introduction to error estimation and adaptive mesh refinement in the finite element method.

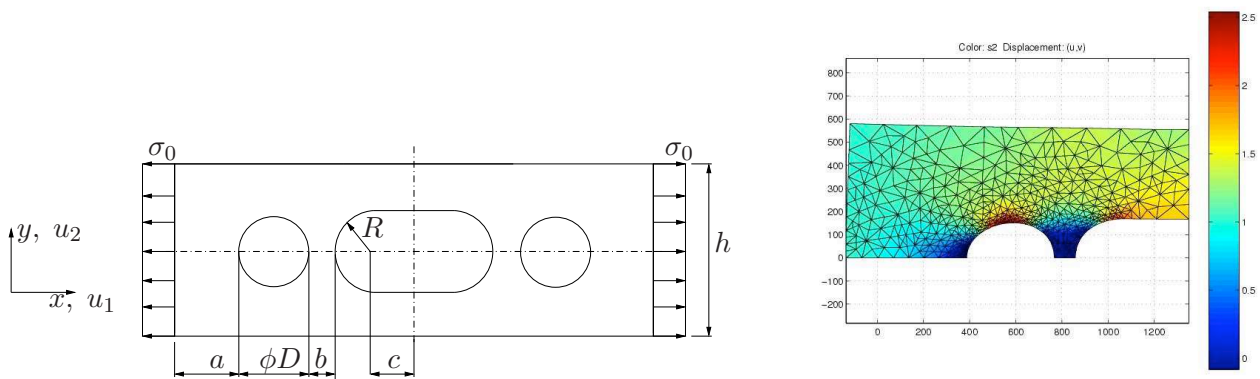


Figure 1: Left: plate with three holes. Right: the color represents the stress distribution in a quarter of the plate. The largest principal stress is presented. The applied stress is $\sigma_0 = 1$. Note the higher stress near the holes and the mesh refinement around the holes. Note also the deformed geometry.

INTERACTIVE/VIRTUAL LEARNING ENVIRONMENTS

Young people learn much differently than they used to just a few decades ago. Researchers in the area of pedagogy refer to this as the “Nintendo Syndrome”, see [17]. The video-games generation does not read manuals. Instead, they jump right in and give it a try. If you get “killed”, you just try something else until you get to the next level. If that does not work, just go to the internet to get a hint. We have noted that this attitude seems to prevail when it comes to studying. Convincing students to read a book has become increasingly difficult. But students do find it educationally rewarding to actually try something before reading about it. Naturally we need to take this new learning style into account and take benefits. We have noticed that the new learning style can be very effective. For example, students learn to use software (e.g., for CAD, finite elements, material selection, virtual production documentation, etc.) faster and more efficient today compared to some years ago and this without reading the manuals. In order to exploit this and to enhance teaching and student learning, we have introduced virtual or interactive learning environments.

In the course *Mathematical statistics* we provide the students with a Virtual Learning Environment (VLE) containing randomly generated problems and questions (quizzes) on every subject of the course syllabus, extensive system of hints and answers, links to the class text and other support materials: statistical tables, demonstrations, help files, see [18]. VLE is developed at the Department of Statistics and Modelling Science of the University of Strathclyde, UK, and at Chalmers University. The reformed course *Mathematical statistics* is entirely ported to VLE. The course was given for the first time the academic year 2009/2010 and had about 200 students. The novel approach consists in shifting the weight from formal lectures and towards self-practise and self-studying with the help of the VLE also aided with statistical routines of Matlab computer package. This makes it also possible to study large complex open ended problems connected to applications of mechanical engineering. Obviously, the VLE fits the CDIO-paradigm providing the students with a web-based framework for probability and statistics. Since VLE is web-based, the VLE is accessible from anywhere anytime, it does not depend on the operating system used, it has infinite number of variations of the study questions, so it provides students with valuable resource to practice beyond the assisted computer lab times. A snapshot of a web-browser running VLE is shown in Figure 2.

MathStat VLE

Methods - 6.3 - Approximate confidence intervals

22 In a survey to assess the support for a certain political party P, a sample of 769 has been taken. The sample proportion is 0.562. Calculate confidence intervals for the true proportion (expressed as a number between 0 and 1) of people who support P.

Confidence intervals : 95% (top) 99% (bottom)

0.550 0.560 0.570 0.580 0.590 0.600 0.610 0.620
Data values

a 95% lower confidence limit.
0.5622098 ✓ (0.56121, 0.56321)

b 95% upper confidence limit.
0.6315483 ✓ (0.630548, 0.632548)

c 99% lower confidence limit.
0.5614158 ✗ (0.550316, 0.552316)

d 99% upper confidence limit.
0.6424423 ✓ (0.641442, 0.643442)

Re-submit answer Give me the answer Give me a hint

Return to question list

Distribution: Normal, Inverse Normal, T, Inverse T
Tail: Low, Both, High, Low, Both, High, Low, Both, High, Low, Both, High

p: 0.05 Mean: 0 Sdev: 1

$P(X < -1.95996 \text{ or } X > 1.95996) = 0.05$
(Equal tails)

Light green area is 0.05

Stams VLE: Hint

strath.ac.uk https://vle.stams.strath.ac.uk/vle/metho

Section 6.3 : Hint for question 2

(CT 7.2)
The procedure is very similar to that used in section 7.1.1. Instead \bar{x} is replaced by \hat{p} and σ by $\sqrt{\hat{p}(1-\hat{p})}$ to give $CI_L = \hat{p} \pm z_{\alpha/2} \sqrt{\hat{p}(1-\hat{p})/n}$.

Use the Help Tables Inverse Normal (Both) with $p = \alpha$ to obtain $z_{\alpha/2}$. Or use Minitab's Calc -> Probability Distributions -> Normal (select Inverse cumulative probability) or MS-Excels' NORMSINV(1- $\alpha/2$) function.

Of course $\alpha = 1 - L$, and $L = 0.95$ for (a) and $L = 0.99$ for (b).

Figure 2: Student VLE training session.

Another feature of VLE is that it provides teachers with an administrative tool for communication, documentation, timetabling, diagnostics, surveys and monitoring each student's activity in the VLE. Each problem tried can be examined for errors which allows for individual support, see example of the activity log in Figure 3.

University of Strathclyde **Stats VLE** University of Technology CHALMERS TMS061

Navigation: Home, Logout

Classwork: Study guide, Methods, Projects, Tests, Exams

Help: Tables, MATLAB, Staff photos

Questions: Manage, Source, Statlib, Riib

Change: Password, Class

Student: Select

Study: Attendees, Diagnostics, De-select

Class admin: View marks, Setup class, Permissions, Exams, Surveys

print diagbysession | export study/test as CSV | export detailed test as CSV | export week/week diag as CSV

Class Record

Session by session | All degrees | Thu 08:00 (Study MT-0,9,11,12,13) | Redisplay

Select all users | Email selected users

Student	Study correct/attempted							Percentage Test mark		
	S1	S2	S3	S4	S5	S6	S7	T1	T2	T3
Anderson, David	29/32	32/33	31/33	19/23	29/30	5/10		79	58	40
Anderson, Jenny	36/42	38/45	13/18	16/28	12/16	24/27	14/14	94	40	82
Anderson, Nils	42/42	41/42	29/29	14/18	8/10	38/38	26/28	100	49	79
Andrén, Gustav	33/33	47/47	41/42	38/39	25/25	16/17	26/29	88	55	81
Andrén, Mikael	30/30	39/40	40/41	39/40	24/24	11/24	14/16	77	85	95
Armstrong, Jonathan	37/38	49/49	39/39	14/15	12/12	34/34	28/28	88	73	92
Asplund, Emma	26/27	21/23	15/16	13/14	8/12	17/20	13/16	64	63	70
Bergström, Emma	41/41	55/56	72/72	28/30	22/22	35/35	17/18	80	100	83
Bergström, Emil	37/37	46/46	44/44	43/43	29/29			88	70	
Bergström, Mathias	31/31	23/27	14/16	40/41	26/26	40/41	31/31	89	67	57
Bjell-Evensen, Magnus	109/109	99/99	55/55	42/43	29/29	19/20	6/10	100	67	55
Bjell-Evensen, Joakim	91/91	30/31	24/24	29/30	12/12	29/30	20/22	80	68	87
Caplan, Aleksandra	50/53	35/38	26/28	27/28	20/21	17/22	14/19	100	63	69
Carlsson, Jenny	31/31	35/35	30/30	30/30	24/24	20/20	16/16	80	81	95
Carlson, Jacob	41/41	50/50	48/48	66/67	37/37	37/37	40/41	100	100	99
Chen, Richard	71/72	92/93	52/52	34/34	21/23	22/30	15/21	82	53	32
Dahl, Karin	31/41	16/32	20/45	31/34	24/24	1/3		80	69	
Davies, Mathias	28/28	51/54	30/30	36/39	27/27	40/42	33/35	80	57	75
Dyrelid, Niklas	37/37	30/33	36/40	28/31	34/37	21/23	13/14	88	60	82

Figure 3: VLE administrator view.

The VLE is also used for assessment, tests and examination. By the end of the course the students become very familiar with its environment and this helps to ease the examination stress. The final exam is carried out in computer lab with using VLE and with access to Matlab. Since marking is done automatically, VLE saves a huge amount of teachers' time. This time can preferably be used to discuss with and tutoring the students in scheduled classes in computer lab.

The VLE meets the challenges with new learning attitudes by providing the students with a tool for learning by practices. The VLE also trains and prepares the students for modern way of engineering work based on computer calculations and simulations. The VLE provides the student with a way to practice as much as they want to become confident with the topic. On average the students answered 150-200 problems during the course. We do not think this would have been possible in a statistics course given in a traditional manner. The results shown by the students were excellent, over 95% of registered students passed to course which is much higher than previous years when 70-80% passed. The students sincerely enjoyed working in the VLE and meant that it is a great way of learning statistics.

In this academic year an interactive learning environment based on Maple TA [19] has been introduced in the courses "Linear algebra" and "Calculus in several variables". So far this consists mainly of automatically graded exercises and tests, but it will be successively developed into a more advanced interactive learning environment for all the mathematics courses.

EVALUATION AND RESULTS

All courses are evaluated using the standard Chalmers system. The evaluation is carried out in cooperation between the program management, the students and the teachers. For each course five to seven student representatives are selected as a reference group. The reference group meets the teachers three times. The final course meeting takes place after the course has been completed. The head of the program /and the program coordinator are also present at the final meeting. Before the final meeting, a web-based questionnaire is distributed (via email) to all students, to be answered anonymously. The results are collected and are discussed at the final meeting and presented in the minutes from this meeting. The minutes from the final meeting are published on the Chalmers web site. In addition, at Mechanical engineering we have annual class feedback meetings with all students that have been appointed course representatives during the academic year. At those meeting, the full view of the curriculum is discussed, *e.g.*, how courses connect to each other and how the program aims are meet. For the particular evaluation of the mathematics education we have put specific questions in the web-based questionnaires, interviewed a group of ten third year students as well as interviewed teachers of following design-build-test projects and master level courses in structural dynamics and employers at a consulting company and at a large global company.

The main goal that each student should gain knowledge, skills and ability to effectively use computational mathematical modeling and simulations in applications has been reached to a large extent. Employers claim that the mechanical engineering students have become significantly better prepared for the managing and solving of open-ended problem, carrying out numerical simulations, programming and using modern industrial softwares. Teachers of structural dynamics courses verify that the students' ability to solve large complex problems has improved and that the computational skills in general are much better. They also claim that Mechanical engineering students in average are much better prepared for the courses and can handle computations and projects involving finite element simulation more efficiently and at higher level compared to engineering students from other engineering programs at Chalmers and outside Chalmers. Furthermore, the teachers of the subsequent Design-Built-Test courses have noticed that the students carry out more adequate analyses

and simulations using the computational tools, e.g., the Finite element method, from the mathematical courses. This has improved the quality of the products developed. Teachers in parallel and following courses have noticed a huge improvement in the ability to program Matlab, which is not surprisingly given the programming course and all computer labs.

The students appreciate the ability to work with realistic models and the possibility to gain insight and understanding of the behavior of the systems studied. They mean that it is natural to use the computer in mathematics courses and regard the computer as an important tool for calculations as well as for understanding mathematics. A change in thinking (and reasoning) is that very few students question why mechanical engineering students have to study mathematics. The proposed approach has strengthened the connection between the applications and mathematics. This is very important for the engineering education, having in mind that mathematics is the fundamental tool for most of the engineering students. The students believe that computer exercises and cooperation with the mechanics courses taught in parallel increases motivation to study both courses. The motivation for studying the mechanics courses appear to have increased slightly more than the motivation to study mathematics. Although the difference is small, this is a somewhat unexpected result.

One concern is that students give priority to the computational mathematics and do not learn the traditional analysis required for example to solve specific integrals and differential equations that are important in applications. From interviews with students, it is clear that the motivation for the more traditional analysis is high and it becomes more understandable with the help of the computer exercises. Teachers in parallel courses mean that the ability to carry out traditional analysis has not deteriorated but neither improved. The results of the applied courses verifies this. The students' ability and willingness to perform traditional analysis need to be monitored continuously, not least of the concerns of other teachers. Teachers have also expressed a concern that the computer and Matlab will only be a "black box" that deliver results without the know how. We believe that there are no grounds for this concern because students write their own code to solve systems of equations, integrals and differential equations, etc. and many problems and exercises are taken from applications where it is important to assess the results plausibility.

The number of students that passes the courses has increased, in particular for the courses *Calculus in several variables* and *Mathematical statistics*, where the proportion of passed at first attempt increased from 40-60% to 70-90% and 60-70% to over 90%, respectively. Further in course evaluations the the students' general impressions of the courses have been increased from adequate to good or excellent. The attendance at lectures, exercises and assisted computer lab sessions are high and significantly higher compared to comparable traditional courses. The teacher responsible for the mathematics courses the first year, Professor Stig Larsson, was 2008 awarded best lecture at the Mechanical Engineering program, Chalmers, by the students. In 2008 Stig also received the Chalmers Pedagogical Award for his efforts to integrate mathematics in engineering subject. The conclusion is that the students are very satisfied with the reformed courses as well as with the teaching in the courses.

CONCLUDING REMARKS

We strongly believe that the proposed education also has the potential to increase the interest for the underlying mathematics. Clearly, the proposed approach strengthens the connection between the applications and mathematics. This kind of mathematics makes it possible to solve the complete problem: from modeling and solution to simulation of the system and comparison with physical reality. This is one of the corner-stones in the CDIO-curriculum. However, our experience also

shows that it is important to emphasize symbolic hand calculation and basic programming concepts in the teaching, so that these are not lost in the excitement over the possibility of doing simulations.

Let us return to the bullet list in section MATHEMATICS IN CDIO. The main focus of the reformed mathematics education is modeling and simulations which are present and extensively trained in all courses. Here Matlab and finite element simulations are key components but also industrial softwares as ADAMS, ANSYS, CATIA and FLUENT are introduced and used in the applied courses. Decision making is brought forward in the sense that we consider real systems and structures and solve real problems. This means that the results can act as basis for making engineering decisions as well as reasoning at a much higher level compared to results of fictitious oversimplified problems with just an answer. Moreover, decision making is trained at a much higher level in the following design-built-test projects using the computational tools to analyze, investigate, evaluate and design different solutions.

Integration of mathematics into the curriculum and the applied courses are demonstrated and discussed. We conclude that mechanical engineering education offer very good opportunities for the integration of mathematics into courses such as, e.g., Mechanics, Strength of materials and Control theory, but also the other way around, i.e. integrating the applications into the mathematics courses, are very rewarding and important for the education.

Active learning is met largely in simulations, open-ended problems and in the virtual/interactive learning environments are used.

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DEVELOPING OPEN SOURCE SYSTEM EXPERTISE IN EUROPE (DOSSEE)

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ABSTRACT

Developing Open Source System Expertise in Europe (DOSSEE) is an Erasmus intensive programme (IP). The aim of this IP is to exchange knowledge of and experience in local methods and techniques in the field of open source software knowledge in ICT by engaging a group of international students and lecturers in a joint, explorative investigation of contemporary methods of open source software systems. In addition the program focuses on the students learning interpersonal skills, such as personal and professional skills, multidisciplinary teamwork, communication, communication in a foreign language and leadership. The target group consists of European engineering students who are interested in knowing which factors play a role in information systems and what the similarities and differences between the various national approaches in open source software systems and techniques are. The event forms a unique opportunity in promoting active learning in an international environment. Students get experience working in teams across country boundaries. In the paper we will describe the structure and our experiences from participating in this IP with relation to the CDIO initiative. Finally we draw conclusions and give our recommendations based on those.

KEYWORDS

Communication, group dynamics, international team building, international design-build projects, interpersonal skills.

INTRODUCTION AND BACKGROUND

In the period 14 March 2011 to 24 March 2011, DTU participated in the Erasmus Intensive programme (IP) Developing Open Source System Expertise in Europe (DOSSEE)

The Erasmus IP is a short programme of study under the The European Commission's Lifelong Learning Programme. The aim of an IP is to bring together students and teaching staff from higher education institutions of at least three participating countries. It can last from 10 continuous full days to 6 weeks of subject related work.

The DOSSEE IP last for 10 days and involves the following partners: Helsinki Metropolia University of Applied Sciences (Metropolia), Finland, Universidad de Alcalá (UAH), Spain, Technical University of Kosice (TUKE), Slovakia, Transport and Telecommunication Institute

(TTI), Latvia, IUT1 Université Joseph Fourier Grenoble (IUT1 Grenoble), France, FH Joanneum University of Applied Sciences, Austria and Technical University of Denmark (DTU), Denmark.

A total of 70 students (10 students from each partner organization) and 20 teachers from the participating institutions met at this year's host institution. Universidad de Alcalá (UAH), Spain

Pedagogically the DOSSEE IP aims to:

- Develop and pilot new pedagogical approaches in project development in a multinational environment
- Promote experimental learning
 - o learning to learn
 - o how to deal with unknown methods and techniques
- Promote use of modern communications media in project management
 - o web-based course material delivery
 - o document management systems, i.e. version control systems and wiki's

The event fits extremely well with the CDIO principles and brings the ideas forward to an international scene.

PROCESS OVERVIEW

The DOSSEE development process consists of two parts, figure 1:

The development of a project plan and technical plan at the "Home University". This part is done by local students in each partner institution. The technical plan forms a "Design-Build" project to be conducted by an international team in the intensive period.

The intensive period. In this period the product is developed in international teams

The objective of the Danish project is to develop an audience response system (ARS) running on an Android based Smartphone.

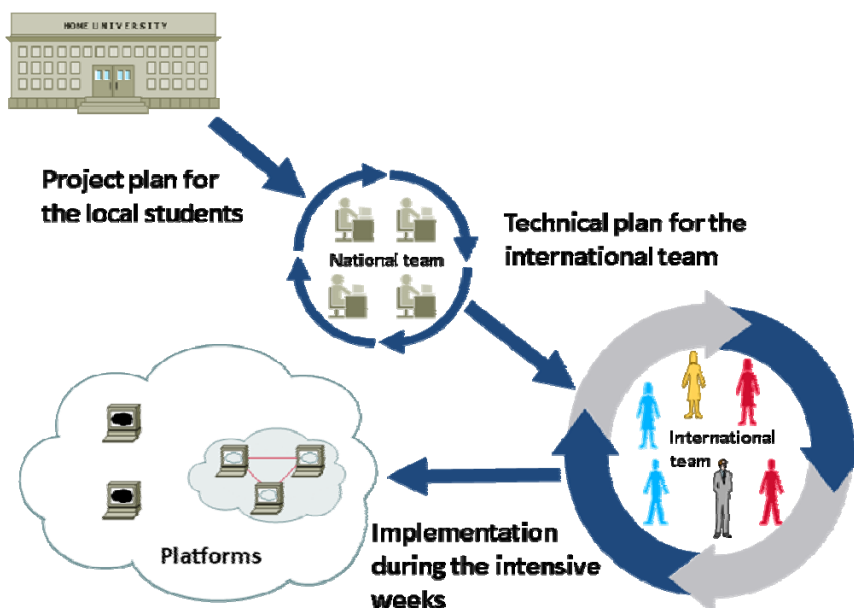


Figure 1. Overview of the development process

Before the start of the intensive period, students from each partner organization will be distributed to other partner projects, based on their technical skills, apart from the national project managers and their deputies, will be back in their respective projects.

By successfully completing the Intensive Programme, students can earn 5 ECTS credits. Besides work a social programme will be offered to all participants.

The overall process is shown in figure 1.

HOME UNIVERSITY ACTIVITIES

Project plan / idea

The idea to the project plan, came to us during an event in Copenhagen, where Apple/iPhone and the Internet Service Provider “3G”, were promoting their products. During the event among different presentations – the audience were asked to vote using their SmartPhones. Unfortunately the bandwidth was too narrow – so a lot was unable to vote. Afterwards we were talking about having this tool to use in our lectures. It could be nice to test the student's knowledge on a subject before a lesson and again after – to measure the benefits for the students.

We tried to buy an app from Apple through App Store (<http://store.apple.com/>) – an app able to handle such Audience Vote Response – it was either not existing or too expensive. Then the idea evolved – why not ask our students to develop the Software on the Android Platform using e.g. a HTC SmartPhone?

We were a little bit excited about – how many students we could attract to both the idea behind the project plan but also the loss of 2 weeks lectures at the home university during the Intensive Period abroad? We tried to spread the information on posters like “Who would like to go to Sunny Spain for 2 weeks?” and by asking our colleagues to spread the offer both among Bachelor as well as among Master Students.

We succeeded very well, as 48 students wanted to go and we only had 10 seats.

Information meeting

The next step was to set up an information meeting – to make the conditions clear to everyone.

The conditions were: – “Are you ready to lose 2 weeks teaching / learning at the home university and cope with the lectures on your own before going or after coming home? Are you willing to deposit 150 € before Christmas?” The deposit covered the student's part of the flight ticket and social program in Spain.

We also informed the students around the importance of having a health- and a travel insurance – and the possibility for being moved from the Danish project to one of the partner Universities projects.

We set a limit to students that they should have studied at least one and a half year – before they were mature enough on ICT. All information was concurrently distributed on the website www.dtu20.be/DOSSEE which was set up as a service to the students.

Selection of students

To cut down the number of students from 48 to 10 – we made a questionnaire. This questionnaire made the students write about their motivations and personal skills as “How many different programming languages are you able to handle?” “How many different OS-platforms are you familiar with?” etc. Only 24 students were handing in the questionnaire

We then selected the 10 best fitted and also took out 2 reserves in order to secure against illness or other events. We made the 10 students pay 3 months before as a guarantee for being serious about going.

Preparing the technical plan

We then started up the 12 students on some meetings – where they started working on transforming the project plan to the technical plan. They began on this task around 1st of December 2010 and ended the job during February 2011. The technical plan contained the foundation for Design-Build project to be carried out in Spain. The technical plan was important as it should be used to secure a proper developing during the 2 intensive weeks in Spain – also the technical plan was marked as it contributed with a third to the grade for each of the Danish students.

Distributing the students into international teams according to skills (and wishes)

The coordinator in Finland made the distribution of students – except for the 2 team leaders, who were tight coupled to the home university's project and knowing the technical plan. The coordinator was supported with the information on the student's skills – known from the questionnaires- The students were all informed on the other universities' plans and ideas – so we made them produce 2 prioritized wishes. Due to lack of students from France – 3 free seats were offered and as Denmark had a huge pool of students – we started to offer the 2 reserves the chance to join – and also in the last minute found yet another student willing to go to Spain. Thus in total 13 students from Denmark went to Spain. The group flight ticket booked just around Christmas, had to be updated with the new members.

Establish contact to the international team members before the IP.

The different mixed teams were established around 2 weeks before departure – thus were informed on the other team member's email addresses – and thus the team leaders were able to start introducing themselves and start networking before the arrival in Spain.

THE INTENSIVE PERIOD (IP)

All students arrived to Alcala on Sunday just before the start of the IP. The hosting university was responsible for accommodation and arrangement of laboratory facilities and the necessary equipment. Before the IP, a questionnaire was filled regarding requirements for necessary technical equipment to carry out each partner's project.

An overview of daily schedule is shown in table 1.

The first day a number of practical information's were giving together with a general lecture on multicultural teamwork. Furthermore the students were informed about the grading process.

As part of the introduction event each of the 7 team leaders presented the technical plans of the projects to be developed in the international teams.

After the introduction presentations the international teams were gathered in laboratories that were assigned to each project.

Table 1
Overview of daily schedule

Day	Activities
1	- Welcome, general practical information - lecture on multicultural teamwork - lecture on grading and teamwork in the IP - Intercultural Ice-Breaker
2	- Teamwork workshop - Teams presenting their technical Plans - Introducing the technical environment - International Communication Workshop - Mentored International Teamwork
3	- Mentored International Teamwork - International Communication Workshop
4	- Mentored International Teamwork
5	- Mentored International Teamwork
Weekend	- Social arrangements
6	- Mentored International Teamwork
7	- Mentored International Teamwork
8	- Mentored International Teamwork - Preparation of project presentations
9	- Project presentations
10	- Project presentations and final evaluation

In Figure 2, the Danish-led international team is shown alongside with the team's mentors.



Figure 2. The Danish-led international team. From left to right:
Mads Nyborg (Denmark, mentor), Juha Hakala (Finland), Kim Rostgaard Christensen (Denmark, project leader), Vera Fallmann (Latvia), Marcos Sanchez Blazquez (Spain), Jeppe Mariager (Denmark, deputy project leader), Ramón García Olivares (Spain), Tomáš Vereščák (Slovakia), Erik Telepovský (Slovakia), Alžbeta Kováčová (Slovakia), Jin Jin (Finland), Andres Rubio del Saz (Spain), Finn Gustafsson (Denmark, mentor)

During the first two days an international communication workshop for the individual teams was held. Before these workshops an intercultural Ice-Breaker event took place for all students. The purpose of the Ice-Breaker was to allow students to shake hands and get to know each other and thereby increasing group dynamic.

Based on the technical plan of the Danish project, the project was divided into three sub-projects within the team: server backend, native Android frontend and web frontend. Team leaders formed subgroups based on a questionnaire in the team, where the student's wishes and detailed skills within the team were taken into account. The students had to deal with a number of technical challenges and were based on the technical to agree on what technologies should be used to develop the project.

The project was developed using a Scrum-like [5] development process. Every morning a status meeting was held where each subgroup presented their work so far and what they planned to do the following day. In figure 3, the Danish-led team is shown at work in the laboratory.

At the start of week 2 the integration of the individual subprojects were started and the test phase began hereafter.

On a daily basis a review / progress meeting was hosted by the teachers (team mentors) at the end of the day. Problems encountered were discussed with team leaders and potential solutions put forward.



Figure 3. Teamwork in laboratory – testing the Android front end

To support the project development a CMS system based on Redmine (<http://www.redmine.org/>) was created. The project team used the version control facility Redmine as a common base for controlling versions of the developed system.

COMMUNICATION WORKSHOPS DURING THE IP

The objectives of the IP course have not only been of a technical nature. After the first DOSSEE IP in Helsinki, Finland in March, 2010, one of the comments from the evaluation board was that there should be more focus on the interpersonal skills since the working conditions of the typical engineer nowadays will include many other fields than just the hardcore technical skills. Based on this it was decided to include an Intercultural Ice-Breaker and an International Communication Workshop in the DOSSEE IP in Alcalá, Spain, 2011 in order to support the overall goal of the IP.

The work with interpersonal skills consisted of two parts:

- Intercultural Ice-Breaker
- International Communication Workshop

On day one, Monday, all students attended a two-hour Intercultural Ice-Breaker with exercises made to get the students to know each other. Unfortunately, this two hour Intercultural Ice-Breaker with exercises made to get the students to know each other. Unfortunately this Ice-Breaker suffered from taking place in a public area with very bad acoustic conditions making it impossible to communicate well. A microphone would have made a great difference and made it possible to give instructions to the exercises in a good way. Several exercises went down rather badly due to problems in communication, but the final exercise “Speed dating” where the students were placed in two circles, one into the other, worked out really well. The students standing two and two face to face got to talk to each other for about two minutes whereupon the students in the outer circle moved to the left and now could talk to a new person for two minutes. Once the students had found out the principle (again problems with communication) they apparently found the exercise great. When we walked from student to student telling that the workshop was over and they could go home, many of them were so busy talking that they stayed for much longer. Also we saw that students having been forced to move kept talking to their former interlocutor thus making a group of four persons talking. Another group of six persons started when one person asked if he could sit down since he had a problem with his leg due to a football injury. Put together with another student he immediately talked about how he could not be standing up due to having played football. About ten minutes later a whole group of football interested students were sitting together discussing this sport. This is really an example of how students with the same hobby/interest get together very quickly if given the right possibilities.

Tuesday and Wednesday, the seven international teams were split up in three so that one third of the students took the two hours International Communication Workshop at the same time: Teams 1 & 2, teams 3 & 4 and teams 5, 6 & 7. This part of the course consisted of exercises with the focus on communication and body language, and took place in a nice room with appropriate facilities and size.

Several students responded that taking an entire team of students at the same time to the International Communication Workshop was not a good idea – it was better to take about one third of the team (since the course was done three times) and preferably let the team leaders decide which team members should go at which time. This would make it possible for the team to continue working all the time and perhaps the students at the communication course would actually be able to focus 100% on the communication part rather than be thinking of the work in the IT-class since they knew other team members were working on the project. Dividing the teams into thirds during the communication course will also give the team members the possibility to get to know somebody from all seven teams.



Figure 4. Students in an exercise at the International Communication Workshop.

Evaluation of IP DOSSEE 2011: Feedback questionnaire

Friday afternoon towards the end of the IP DOSSEE 2011, there was a one-hour electronic questionnaire where the students were asked 64 questions including five questions where the students had the possibility of additional personal comments. There were no direct questions concerning the Intercultural Ice-Breaker and the International Communication Workshop.

Based on the electronic evaluation, an internal 30-page document “IP DOSSEE 2011: Feedback questionnaire” has been written. The results from this evaluation have been compared to a similar evaluation from the first DOSSEE IP in Helsinki, Finland in March, 2010. In table 2 the most important information has been shown, which can be linked to the Intercultural Ice-Breaker and the International Communication Workshop. The results are influenced by many other occurrences in the IP project; however they do give an indication of the outcome. There was no education in communication in 2010, but only in 2011 which is one of the major changes from 2010 to 2011. Based on this, few comments can be linked to table 2, which are to be taken only as an indication since there were no questions directly linked to the communication.

Table 2
IP Student Feedback Comparison 2010 and 2011

IP Student Feedback Comparison	2010 %	2011 %	Relative improvement %
Better language skills	76.1	79.2	4.1
New friends	87.3	93.1	6.6
Experience and knowledge of different cultures	78.9	86.1	9.1
Independence	29.6	30.6	3.3
Life experience	73.2	84.7	15.7

When the results from table 2 are studied and year 2010 and 2011 are compared, it can be seen that the feedback is much more positive in 2011 than in 2010 when there was no Intercultural Ice-Breaker and International Communication Workshop. “*Experience and knowledge of different cultures*” has made a relative improvement of 9.1% and “*Life*

experience” as much as 15.7%. Making “New friends” has increased relatively by 6.6%. Of course these data can only be taken as indications since many other things all together influence on the results. However, since there has not been made any questions directly linked to the communication, these indications will be the only numbers which can be used except from comments from students and observations from the Workshop.

Comments from students – IP DOSSEE 2011: Feedback questionnaire and e-mails

There are generally more negative comments in the IP DOSSEE 2011 feedback questionnaire than what we are used to from the one week International Communication Course (ICC) we do in Helsinki, Finland as part of the ICT (Information and Communication Technology) week [2] [4]. One of the reasons for this could be that in the IP DOSSEE 2011 all the students were forced to do the International Communication Workshop, and at the same time they were very stressed by the work they had to do on the project. In Helsinki people choose the International Communication Course, however some take the course just to get the credit. It is the impression at the ICC Helsinki that in the beginning of the week several students may be quite negative towards the way the course takes place with personal exercises, where the students have to involve themselves; but by the end of week they have gradually changed to a more positive attitude, since they realise how much they actually learn in the exercises. As part of ICC Helsinki we teach 17.5 hours compared to the 2+2 hours we had at IP DOSSEE 2011.

Two hours Intercultural Ice-Breaker exercises and two hours International Communication exercises are simply too short time for all the students to really get an understanding for communication and how they can learn by doing personal exercises. Many will also have personal barriers against doing exercises where they are to involve themselves. It can be expected that only some of the IT students may have a basic understanding beforehand and therefore are able to understand the importance of committing themselves.

In the following, three positive and three negative comments from the students have been selected. The comments have been taken from IP DOSSEE 2011: Feedback questionnaire and e-mails sent to Christensen. As it has been stated before, the numbers of negative comments outnumber the positive comments.

Comments from students – Positive

“I really appreciate the intention of the communication workshop because I've been missing this kind of things since I started my degree. I mean, I try to consider it like a suggestion, an encouragement which calls to the dialogue and the discussion, the imagination and even the needed freedom to face the fact that not only must we work with computers but with other humans, and we must do it in a proper way. Normally, those humans will be engineers and, very often, engineers think that they are three steps over the rest of the people. So I reckon that, probably, something interesting to add in the next editions would be precisely that, something that make students notice the lack and necessity of humility and at the same time, how to deal with that. Finally, I would like to say thank you for making this possible. Being during these two weeks with such amount of different people from different countries has been one of the most rewarding experiences in my life.”

“The team work presentations and concepts given to us in them should be given as needed by the tutors in the tutored team work hours. The only presentation I would not get rid of was the international communication workshop. It was very interesting and useful as not only were we taught basic techniques for job interviews but also about body language.”

“The work on the project itself was awesome. The international communication + parties = awesome. And I loved Christensen’s with their psychological stuff.”

Comments from students – Negative

“And I think students’ don’t need so many Ice-Breaking activities. We are young and perfectly deal with communication issues between each other.”

“OPEN SOURCE (JIRA is not OPEN SOURCE), not so much theoretical stuff, if you want to make a Social ICE-Breaking give us a bottle of alcohol and not some stupid teambuilding exercise with the Danish couple.”

“No stupid presentations about teambuilding and communication.”

EVALUATION AND GRADING

Upon successfully participation in the IP a student can earn 5 ECTS.

The evaluation of the projects was based on:

Deliverables:

For the project documentation a WIKI (<http://www.mediawiki.org/>) was set up. All teams have to upload material to this site. The teams are free to decide the structure of their particular entry on this wiki.

Project presentations:

During the last two days of the period the teams presented their projects for all teams during a 45 minute oral presentation session. The presentation included a short demonstration of the product developed and answering of questions

The final assessment consists of three parts:

- Assessment of the preliminary work at the home university. This part is done by the teachers in the home universities and is mostly based on an evaluation of the developed technical plan.
- Peer Evaluation of team members. All team members within a team assesses each other (including themselves)
- Team evaluation. Each team assesses the other teams (including their own team).

Grades are based on an overall assessment of these parts. Students are graded individually. Each part of the above listed evaluation points counts 1/3 of the final grade.

CONCLUSIONS AND FINAL REMARKS

In general our experience with the IP is very positive. The event contributes extremely well in training of the student’s personal, interpersonal skills and teamwork.

Very few problems were encountered in the Danish team.

General feedback from the students gave rise to the following points to consider in future IP’s:

Project proposal

It should be considered to let the students choose the subject for the project and not the teachers as were the case of this IP. The teachers' role should be to approve the proposal.

Team leader role

It should be clearly stated in the application questionnaire which functions the team leader role includes such that an applicant can indicate whether he or she would like to take on this role.

In this IP the team leader and deputy was selected by the teacher based on the work put in the development of the technical plan at DTU.

Matching of student expectations

Not all students had the same expectations to the IP. The purpose of the IP is twofold – it contains both a social dimension and a technical dimension. In future IP's it might be useful to agree on the focus before the work start.

The IP Communication Course

It is a challenge in only 2+2 hours to make a breakthrough in the IP DOSSEE 2011 regarding communication for all IT students. This amount of time is to be considered limited when discussing the importance of obtaining interpersonal skills since the students were much focused on their project. Studies from the one week ICC for IT students in Helsinki [4] have shown that it is necessary to work with the students for many hours in order to make the young people aware of the communication problems some of the students face. It may be a good idea to write an introduction note to the teachers and students that are to participate in the program, in order to give a better understanding of the importance of learning the interpersonal skills in the program. This might be one of the most important improvements, which should be made for the IP DOSSEE 2012 program. Since in Denmark there is a great interest for participating in the IP DOSSEE program, it is suggested to make a two face screening process of the students: Phase one will focus on the students' technical skills and phase two will focus on the interpersonal skills.

Organization of Communication workshop

In the future the International Communication Workshop should be organized differently by only taking about one third of the team and preferably let the team leaders decide which team members should go at which time. This would make it possible for the team to continue working all the time. Dividing the teams into thirds during the communication course will also give the team members the possibility to get to know somebody from all seven teams.

Finally, there was a general desire to shorten the introductory sessions so that the development period could be increased.

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ACTIVE STUDENT CARE – LOWERING STUDENT DROPOUT

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ABSTRACT

The article describes different actions that have been taken at the Engineering college of Aarhus in order to reduce the drop-out rate. The actions include brush-up math course, study techniques, exam training, networks of minority students, but most important conversations with students and students mentoring scheme. The actions were identified and evaluated by interviewing key stake holders like teachers and student counsellors.

KEYWORDS

Drop-out, student retention, success factors.

INTRODUCTION

Education is a driving factor of the modern society. The US Census Bureau [1] has found that a person with a graduate or professional degree earn more than three times as much as a person with less than a high school degree. Jobs for persons without a degree are furthermore being exported from the western world; during the latest financial crisis, more than 200.000 production jobs have been laid down in Denmark. As a consequence of this, the political agenda is that we need to educate more young people. In Denmark, the government has the goal that at least 50 percent of all young must have passed tertiary education in 2015 [2]. There are two types of challenges with this: getting enough students interested in taking a degree (e.g. in the US only 40% enrol in a ternary education) and the students who started should finish with a degree.

There is currently much interest in students' success in higher education [3]. The National Audit office found an increase in the number of students dropping out from higher education in England. The interesting question is naturally why this happened. Many different answers were given; most of the answers included the underlying assumption that it was the students fault. As Thomas [4] writes "*it is too easy and somewhat irresponsible to 'blame' new students constituencies for the small increase in early withdraws from HE; such a response lets the HEIs and the HE sector in general off the hook*" (p. 424). In this article we will describe what we as an institution do to lower the students drop-out.

This article addresses the challenge of lowering the student drop-out by describing different methods that have been successful in. This is done by interviewing central Proceedings of the 7th International CDIO Conference, Technical University of Denmark, Copenhagen, June 20 - 23, 2011

actors about their view on initiatives by the engineering college on student drop-out; what is done, what is the most important and what is missing.

RELATED WORK

Traditionally there has been much focus on predictors of success. A substantial amount of research has been conducted to identify general variables that predict the success of students aiming for an engineering degree. The variables investigated encompass gender, parents' educational level, performance in prior courses, emotional factors, the application of a consistent memory model, and ACT/SAT scores to name a few. ACT is formerly known as the American College Test. An American, nation-wide college entrance exam. It assesses high school students' general educational development and their ability to complete college-level work. It is a multiple-choice test that covers four skill areas: English, mathematics, reading, and science. The Writing Test, which is optional, measures skill in planning and writing a short essay. SAT (formerly known as the Scholastic Aptitude Test and Scholastic Assessment Test) is a standardized reasoning test taken by United States high school students applying for college. It covers two areas – verbal and mathematics.

Along the line of success factors, Besterfield-Sacre et al. [5] have developed the Pittsburgh Freshman Engineering Attitude Survey to look for cognitive, affective, and psychomotor variables to determine which ones were significant predictors of persistence.

Moller-Wong and Eide [6] had the same idea as Besterfield-Sacre et al. Their study “was targeted to accomplish several objectives. First, we had to design and assemble a data base that would allow for individual tracking of students. Once a complete profile of our students population had been assembled, it was possible to identify accurately a range of descriptive variables. Next, using the established data base we developed a retention analysis tool that would statistically suggest and identify students who are potentially at risk of attrition.” (p.7). They had a four level success scale (low, modest, commendable, high) and tested their model against students who enrolled in 1990. They found that; based on their definitions of the four categories, that their model correctly placed 74% of the students.

Felder et al [7] compares performance of students taught in classes where the courses made extensive use of active and cooperative learning and a variety of other techniques designed to address a broad spectrum of learning styles. They concluded that the students from the classes with active learning “*outperformed the comparison group on a number of measures, including retention and graduation in chemical engineering, and many more of the graduates in this group chose to pursue advanced study in the field*” (p. 469)

In general, the findings are very mixed and it is indeed hard to draw any general conclusions from these studies; in some cases a few variables predicts a lot while in other cases the same variables has no prediction power. It seems like there is a grooving acceptance of the fact, that learning is very complex and it is not possible to predict it with a few measurements. Consequently, this article does not offer general conclusions but describes activities we have found useful.

DATA COLLECTION

Data for this study was collected by semi-structured interviews with two teachers, the central student counsellor, a student counsellor for three specific study programmes and the head of quality development. Each of the interview lasted about half an hour. They were audio recorded and notes taken. The notes were used as pointers into the audio recorded interviews.

In a later study, we will include students and their view on the actions taken, but for this study we did only use information given by the students who choose to stop (they are asked to fill in a form about the reason for their choice); this information was only used as background information by the interviewed persons, nor as a primary source of information.

ENTERING ENGINEERING EDUCATION

Many authors focus on the first days of a student's new university life. In general, they all agree that it is one of the most influential periods in relation to retention. Leese [8] did a study focusing on the critical first days and weeks when the students need to fit in to their new environment. She found that *"Perceptions about their transition varied, but most of the students expressed concern about the perceived need to be an independent learner. Students stated that they needed more structured activities on campus to encourage them to fit in, and more support from academic staff, with clear instructions about what was expected"*.

In 1997, less than half of the students entering an engineering program actually graduated. According to Besterfield-Sacre et al [9] more than half of the drop-out occurs in the first year. As they note *"Clearly, the freshman year is critical for both academic success and retention of engineering students"* (p. 139). Besterfield-Sacre et al's findings are backed up by LeBold and Ward [10] who indicated the best predictors of engineering persistence were the first and second semester college grades and cumulative GPA.

This naturally calls for initiatives that can help students figure out what engineering really is prior to entering an engineering programme, so that they can be more prepared on what they actually will experience. Furthermore, initiatives aimed at freshmen seem to have a better ROI (return on investment) than initiatives later in the study program.

CONCRETE ACTIONS

This paragraph will describe the actual actions taken at the engineering college of Aarhus to help students graduate with a degree.

In general we have two different types of drop-out: qualified and unqualified. The qualified drop-out are students who for some reason or other find out that engineering is not for them, and start on another programme. In general we find this type of drop-out non-problematic since they (hopefully) will get another degree, and thereby contribute to the government's plan for at least 50 % of youth getting a degree. The other group – the unqualified drop-out – are students who want to become an engineer but leave our Proceedings of the 7th International CDIO Conference, Technical University of Denmark, Copenhagen, June 20 - 23, 2011

programme anyway. We ask all our students terminating their study prior to graduation to tell us the reason why, almost all do. Based on that, we can see that more than 75% of the drop-out is of type qualified.

Prior to entering the engineering program

Both teachers and students counsellors focus a lot on preparing the students. This means that the students should have a clear view on what they can expect of the daily students life if they choose to start.

High school students visit

In Denmark high school students in their final year before entering their bachelors programme, can visit their preferred higher education institution for three days. In Aarhus, we offer three different practices: building and building design, ICT, electrical and health technology, mechanical and Bioprocess Technology. The students will experience presentations and practical exercises, meet students and teachers, experience the learning environment, and will get a good feel for what an engineer's work is.

Math brush-up

Some of our students have been away from the educational system for several years before entering. Many of these students have a little “rusty” knowledge of Math so we offer these students (and others who wants it) one week of math brush-up, where they will focus on reinforcing the math learnt in high school.

During the engineering program

During the three and a half year students study at the engineering college, there are several initiatives to help students stay in their study program. It is – however – important to note that the majority of students do very well and do not need extra care apart from the design of their courses. As one of the interviewed persons expressed it “*it is important to remember that most of our students do very well and do not need help to pass the exams and graduate*”

Initiatives for all students

A few initiatives are for all students. Participation is not mandatory, but the student counsellors keep track of who participates and contact students who do not participate.

Study technique course

One of the problems students often report when they change from secondary to tertiary education is the amount of individual work. In general, we expect the students to be able to figure out by themselves how they need to prepare before any given lecture. This change in work habits is difficult for some students and we offer all the possibility to learn how to structure their work week.

Formal conversations between the student and a student counsellor

In the middle of the first semester, all students are invited to a 10 minutes talk with a student counsellor. The talk is focused on the students experience with his or her “life” at the institution for the first, important weeks. The meeting have an agenda, but the most important thing is to find out if we as an institution can help the students to “stay on track”. For some of the study programmes, it is possible to change from one to another during the first semester; the conversation also helps the students do decide if she wants to change study program.

Initiatives for select groups of students

As written above, most of the students do not need to use the initiatives. We have some initiatives that are elective for students and some specially targeted at select groups of students.

Exam training

Exams at university level can be a challenge for some students. They have, in their elementary school and high school, meet most of th types of exams that we have, but it is still a challenge to structure much more material and present it in a coherent and understandable way. To help students perform well during exams, we offer exam training courses, where the students learn techniques to handle exams. These include simple things like preparing an outline for possible exam questions and presentation techniques.

Student mentoring scheme

Student mentor scheme is offered to all new students at the beginning of their studies in the various fields of study. It can often be difficult to imagine how best to handle the transition from school to study, from trainee to independent student. A mentor can help the mentee to gain greater awareness of

- his future life as a student at Engineering College
- the subject-related choices
- an overview of the study
- the possible new city where you live

A student mentor is a student at the 2nd-7th semester studying at the same line as his mentees. The student mentor have before first meeting with his mentee, attended a specially arranged student mentoring course in communication, conflict resolution and group management. The mentor gets the course and mentor program credited with 2.5 ECTS credits and will therefore appear on the academic qualifications. The Student Mentor Scheme extends over the first month of first semester.

The mentor typically has a group of 5-6 mentees. Meeting frequency generally depends on the needs of the individual groups, but typically the groups meet at least five times during the semester. There is a relationship of trust between the mentor and the mentees, and the mentees can, in principle, ask tehir mentor about everything regarding their study.

Close interaction with students who have a high risk of drop-out

The student administration and student counsellors have a close collaboration. When the administration finds out that a student failed an exam (or did not show up for the exam), they tell this to the students counsellor, who make contact to the student and ask if there are problems that the counsellor can help with. In some cases it is just because the student was unlucky and will pass the exam next time. In some cases there are more serious problems involved, and the counsellor can find initiatives that help the student come back onboard. One example is an agreement between the counsellor and the student to send the counsellor a monthly report on his/her progress. Other examples are pedagogical support if the student have special needs.

Networks of "minority students" for example women in ICT, mothers, dyslexic

All of the interviewed persons find it very important that the students feel included in one or more group of students. Consequently, the engineering college arrange networks of students who have a difficult time due to external element. This includes students who have babies, women in very male dominated study programs and dyslexic students. By setting up these networks, the students do not feel alone and sees that other students have the same problems but succeed.

EVALUATION

All of the interviewed persons agree that the most important element in keeping students from dropping out is that the teachers care about the students. The students must feel that the lecturers respect them and have a genuine interest in their success. Consequently, one of the most important assignments for the director of studies is to motivate and support lecturers in developing their empathy for students.

When asked about what he finds the most important element contributing to students' success, the head of quality insurance mentions the ongoing work with learning goals. It is not the learning goals by themselves that is important, but the shift in mindset from a focus on course content to what is really is that the students should learn. Consequently, a continues focus on the learning goals will not only help the teachers focus on what to teach, but hopefully also help the students with succeeding their study.

The student counsellors have "an open door" so that students who need to talk just can walk in. However, it can be difficult to visit a counsellor for the first time. Therefore the formal conversations between a student and a counsellor not only have the goal of spotting specific problems, but also to get all students to know the students counsellor. All of the counsellors believe that these formal conversations help a lot to the knowledge of them.

When asked about what more can be done to lower the dropout rate, none of the interviewed persons have comprehensive new ideas, In general they all feel that it is a balance between on one hand taking care of the students and on the other to help the students become independent. One of the interviewed persons suggests that it could be positive to have a day where the lecturers and students collaborate on something not within the field of study but something else. The rationale should be to build up better social relations between the students and the lecturers.

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CONCLUSION

Teachers tend to talk about good and bad students or good and bad classes [11]. At the engineering college, we did have a large variety in the percentage of students dropping out from semester to semester, but in the last four years the percentage of students dropping out have been much more stable (but with a steady decline). We believe that the result of all the efforts we have put into our active student care has much to do with this.

All of the interviewed persons stress the importance of teachers caring about the students. As one of the teachers said "*the most important action is that we view the students as persons – not student-numbers*". This is the same view on students as the organization tries to promote: "*View the student as a junior employee; be a role-model*". The conclusion here echoes the conclusion of Thomas [4]: "*if students feel that staff believe in them, and care about the outcomes of their studying, they seem to gain both self-confidence and motivation, and their work improves.*" (p. 432)

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Biographical Information

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CDIO – THE STEAM ENGINE POWERING THE ELECTRIC GRID

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ABSTRACT

In building the new DTU B.Eng programme [1] one of the pilots on the 4th semester is the Design-build project course in Electric Energy Systems. In this course, which is the last Design-build course many of the CDIO Syllabus bullets [2] are addressed starting with problem identification and formulation, experimental inquiry and modelling, finally leading to planning and solution. The goal is to acquire the skills that are needed for an engineer within electric power engineering to analyse a given task, define the necessary steps to solve the task, organize him/her self and others and finally solve the task with success. The concrete work is built up around a miniaturized electric energy system powered by a steam engine. The system mimics an essential sub-section of a real electric power system. The process is realised with a combination of optional lectures, optional exercises, 3 set of self evaluations, weekly supervision and a concluding 3 weeks of intensive lab work. 50+ students are divided in 5 large groups allowing for subsequent sub-organization among 10+ students. The result is well functioning work groups, a robust electric energy system optionally with innovative add-ons such as a solar panel or a cable connection to other similar systems and the acquisition of basic skills within electric power engineering.

KEYWORDS

Electric energy system, steam engine, operation, innovation, group work, self evaluation.

INTRODUCTION

On the background of basic skills in mathematics, physics, electronics and computer science that have already been acquired at this level (4th semester), the students is urged to put their skills into action. The idea behind the course is specifically to encompass aspects of development, project management, teamwork in large teams and communication skills together with engineering fundamentals such as thermodynamics, electric power engineering, power electronics, control and automation. All these elements are combined in one task, generating a work process that mimics the one, the student would face in an internship (6th semester) and ultimately when taking up his or her professional career, at the same time being guided through innovating steps and being encouraged to innovate add-ons beyond the “expected” training system.

In order to guide the students through the learning steps of the Design-build process the following framework is applied.

- An introductory encounter is arranged where the groups are formed, the ideas behind Design-built are presented and a project goal is set.
- A prefabricated electric energy system with a minimum functionality is provided for each group.
- A data acquisition box containing analogue and digital I/O's is offered including software for commanding the box and ultimately the “power plant”.

- A number of lectures including calculations and group exercises are offered within the topics project management, electric power systems and power electronics. These steps provide the means for understanding the fundamentals of electric power systems, among other the prefabricated miniaturized system.
- Three self evaluations are arranged with subsequent feed back to the students on the two first evaluations.
- Based on the first self evaluation and the feed back from the students, lectures and other teaching/learning initiatives can be arranged,
- Lab work and lectures are spiced up with external guest lectures in relevant field and a visit to a real power plant.
- A final three weeks of intensive lab work concludes the Design-built project at the end of which,
- The third evaluation, together with a group-wise poster presentation and demonstration of an operating “power plant”, constitutes the ground for deciding whether the student has passed the course or not.
- All communication including lectures, exercises and documentation on the prefabricated system is up-loaded to a common course space. In a sub-space of the course, space documentation and the students self evaluation can also be up-loaded.

The steam engine combined with essential elements from a 3-phase electric power generation system was selected for a number of reasons being in part:

- 1) The polytechnic character of the task
- 2) To add a dimension of playing into the learning process
- 3) Reality reasons, i.e. highly illustrative with respect to the real world challenges
- 4) Obvious potential for division of the main tasks into subtopics suitable for large groups

In this energy system, a lot of important issues are highlighted and touched upon such as the energy conversion efficiency, how to stabilize grid frequency, 3-phase electric power, 3-phase generators and transformers, ac/dc converters, electric storage, automation and control, measurement techniques, visualisation and graphical presentation etc. These issues become increasingly important when reflected in present day discussion on sustainable energy versus fossil fuel, electric vehicle versus internal combustion engines, smart grid and distributed generation versus conventional centralized power plants.

The added dimension of project management and team work is usually required in order to overcome today’s modern and complex reality.

All these aspect the Design-build of the course aims at honouring.

REALISING THE DESING-BUILT PROJEKT

In the following, different elements of the Design-built project are outlined in detail. The objective, goal and targets will be described together with the means and tools reaching the defined objective.

Objective, goal and targets

The objective of the course is, through the Design-built project, to acquire the spelled out skills listed in the course description of the DTU course handbook [3]. This includes classical knowledge within electrical power engineering such as transformers and motors/generators and their equivalent diagrams, real power and reactive power, three phase systems, converters and inverters, pulse width modulation (PWM), buck-boost circuits etc. It is also desired that synergy with other Design-built projects are exploited. In this case, synergy is ensured with the control field by aligning and exchanging expectation and detailed information on the energy system.

The mentioned objective implies that the specific goal of the Design-built project is to understand, expand, optimize and operate the prefabricated electric energy system. In order to challenge the students, an ac/dc converter has to be constructed, providing a maximum number of pulses and hereby creating optional improvement and/or expansion of the system.

In order to reach the goal a number of targets are exemplified for the students. Examples are provided for their convenience and help. The following aspects, communicated to the student, constitute examples of targets in time, process and topics space.

- Sub-divide the goal into topics related to the electric energy system e.g. in understanding the systems thermodynamics, mechanics and electrics, measuring system possibilities and limitations, built ac/dc converter for pulse generation, create a robust control for the system including a graphical user interface
- Loosely sub-divide the group according to identified list of topics or allocate responsible group members for each identified topic
- Lay down a plan including timeline, resources and milestones for reaching the goal
- Create a structure or organization for illustrating, maintaining or adjusting the work process, also for the case of severe organizational/cooperative problems to occur.

Lectures and exercises

A handful of lectures are offered together with related exercises. As any lecture at a university, these are optional, but the character of them should make the relevance of them obvious to the students, seen in the light of the task to be solved. The lectures provide the basis for understanding a modern electric power system and the power electronics that constitutes an increasing fraction of new installations, in particular in distributed energy resources such as wind turbines and photo voltaics. Further, solving the offered exercises provides a short cut for the student for documenting their acquired skills when delivering their self evaluations.

Self evaluation and feed back

Three self evaluations are made compulsory with the purpose of:

- Providing a tool for following the progress of the students
- Invoking self awareness with the students of their own professional progress
- Evaluating the acquired professional level of the students in relation to the objective of the Design-built project

Combined with feed back from supervisors to students, the two first self evaluations provide the students with a good project start and help to reveal for the student the status of their acquired skills. The first self evaluation is placed after about 4 weeks and is focusing on the project management part and feed back from the supervisors is essential at this time. The second self evaluation is placed before the last 3 weeks period with intensive lab work. This self evaluation is intended to help the student conclude their “theoretical” learning objective. The third self evaluation concludes the course together with a demonstration and a poster presentation.

Lab work

At the introductory lecture, the electric energy system is presented for the students. From the first day of the Design-built project, the students have access to the student lab and the energy system. The students are also introduced to the work shop where repairs and ingenious ideas can be realised. The students are encouraged to “play” with the system from day one alongside the offered lectures and exercises. By simple means, the machine can be manually operated. This sparks the student to seek hard information on the components, refresh their thermodynamics and start measuring many different parameters of the system including e.g. boiler temperature, output voltage and rounds per minute (rpm). With the project planning in place, the lab work becomes more focussed and divided in sub tasks. The lab work concludes in a three week intensive period. During this period the supervisors are available almost full time. In the first part of the three week intensive lab period, a lecture is offered on how to report and present their work. Further, a visit to a real power plant is arranged for inspiration in this week.

At the end of the three week period the work is presented on group posters, where each group member has to contribute with one A4 page, which together with the third and last self evaluation and a demonstration of the system in operation concludes the Design-built project.

Demonstration of system and final evaluation of students

The final self evaluation together with a successful operation of the system and a presentation of a group poster forms the basis for evaluating, if the student has passed the course or not.

The electric energy system with prefabricated main components

An electric energy system based on a steam engine is prefabricated and consists of the following main elements:

1. Power supply from a wall socket
2. Solid state relay for up to 10A
3. 1500W heater for heating the boiler feeding the steam engine
4. Boiler holding a volume ½liter, having an end piece of glass, authorised for up to 2bar overpressure and fitted with a safety valve that releases at 0.8bar overpressure
5. Electronic pressure sensor
6. Manual water feed pump
7. 1liter water reservoir
8. Controllable steam valve with tachometer
9. Two cylinder Wilesco steam engine
10. Chain transmission from engine to generator
11. Three phase generator (Graupner 7709 Compact 9.6V)
12. Three phase transformer
13. Newton meter
14. Power electronics single components as well as standard chips
15. Booster circuit for handling the relay, valve and pressure sensor
16. Data acquisition box with analogue and digital I/O's and USB interface
17. Access to the software LabVIEW

For an overview of the system, see figure 1a and 1b. Figure 1a is a bird's view of the steam engine part of the electric energy system including the step up transformers, but without the power electronics. Figure 1b gives a naturalistic view of the same system.

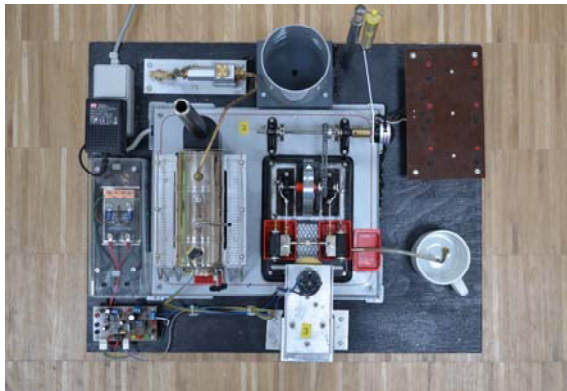


Figure 1a A bird's view of the steam engine part of the electric energy system including the transformer, but without power electronics.

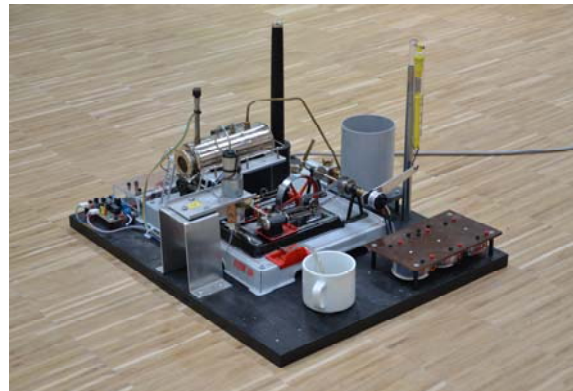


Figure 1b Naturalistic view of the electric energy system shown in 1a.

The following description is the setup as given to the students. A large number of minor and major modifications/extensions can be expected under the course,

The electric energy system is built up around a 2-cylindered Wilesco steam engine. This is basically a toy machine, which we anticipate will not stand the wear in the long run, however, so far it fulfils its purpose. The boiler of the steam engine is heated by a clamp-on heater element

powered by a solid state relay that can be controlled by PWM between 0 and a maximum output of 1500W. One end of the boiler is transparent thus exposing the water level. The water can be replenished continuously by the help of a manual pump. The boiler is further more fitted with a safety relief valve. The resulting steam is lead through stainless steal piping via an adjustable valve. The valve can be controlled with the help of a taco-meter and a small electrical step-motor. When the steam engine is powered up, it may deliver a few watts at around 1000 rpm or wind up to between 2-3000 rpm in idle/no load. The three phase generator (Graupner 7709 Compact 9.6V) is of the type that is used to generate electric power to small remote controlled aeroplanes. The generator is designed to run at up to 18000 rpm. It is therefore not designed to offer an optimal energy conversion at 1000 rpm. The three phase generator is connected to three ring transformers making it up for a three phase transformer. Since the 3 transformers are not connected, the students can play around with different connections (Y and Δ) between the generator and the transformer. In this step the voltage of about a few volts are transformed up to 12Vac. The 12Vac is converted into dc with a power electronic converter that the students have to build themselves. Also the power electronics that determines when the power should be stored in a battery/capacitor or if it is to be released in a load is built by the students.

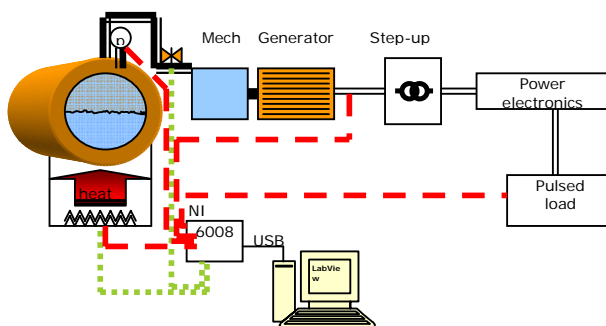


Figure 2 Sketch of the system including the data logging and control.

The heat input controlled by the solid state relay as well as the steam valve controlling the steam pressure reaching the cylinders can be controlled from a National Instrument (NI) I/O box (NI6008/6009). A sketch of the system including the data collection and control path is shown in figure 2. The box displays both analogue and digital I/O ports. Some of the output/control signal needs to be boosted with a TTL circuit because the NI6008 is powered only by a USB computer connection which does not provide enough power for controlling a relay. Further, the NI6008 function as a data acquisition card (DAQ) on which it is possible to sample the tachometer to determine the valve position, to sample the rpm for determining the generator frequency as well as the voltage in different places of the electric circuit. The students are introduced to the software LabVIEW which is dedicated for engineering measurement and control. In this graphical environment and through the NI6008 box they are able to collect the relevant data, analyse the data and implement simple direct control as well as PI and PID control.

DISCUSSION AND CONCLUSION

The response from the students has been positive about the concept and the whole idea of using a steam engine. It often reminded them about the young days when playing with a similar toy, but also gives back the feeling of a real engineer, capable of handling technical challenges of many kinds. Several groups have been inspired to improve the system that they started out with. One group attempted to determine the water level in the boiler by optical means and pattern recognition. Another group combined a LEGO MINDSTORM with the manual water pump to be able to automate also the water replenishing to the boiler. Many groups developed an extensive graphical interface showing the system outline, the system parameters and at the same time allowing for dynamic parameter change as well as system control.

The prefabricated steam engine based system has two major advantages compared to starting from scratch; potentially it reminds the student of joyful memories of the past, further it is appealing because it generates immediate action, even when the students have not yet any control over the system or deep understanding of the system. It may be somewhat different from other Design-built projects but it was judged necessary in this particular course. Given the nominal work load of 10 ECTS credits it was judged risky to set out on building an electric energy system from scratch. The need for the lectures and exercises is thus justified by the advanced level of starting.

The resources in terms of supervisor time, work shop hours and cost of components is significant but may be justified in the large number of students attending and staying with the course (50+) and the priority on the agenda that the Design-built projects have received.

The degree of success with this Design-built project is an integral of the student feed back on course and supervisors as well as the fraction of students that eventually are credited the course.

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A BASIC DESIGN-BUILD-TEST EXPERIENCE: MODEL WIND TURBINE USING ADDITIVE MANUFACTURE

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ABSTRACT

This paper describes a project undertaken by most first-year Engineering undergraduates at Lancaster University in which they are set the task to design, build and test a scale-model wind turbine.

Working in pairs, the students are able to make design decisions on the blade geometry and the number of blades on the turbine. Utilising fused-deposition modelling (FDM) additive-manufacturing (AM) technology, students are able to produce their turbine blades by additive manufacture, which has provided an opportunity to greatly improve the accuracy and finish of the model aerofoils that students can produce, as well as ensuring geometric repeatability of blades on the same hub. It also allows students the capability to produce concave surfaces on the underside of their blades, which was almost impossible when producing the blades by hand methods.

The performance of the model turbines fabricated using the AM technique has been noticeably better than that of models produced by hand, the previous method. Introducing the AM method has also given an extra educational dimension to this design-build-test project.

In this project, students learn about aerofoils and simple aerodynamics and mechanics. The project introduces them to testing and measurement methods, as well as to the advantages and limitations of the particular AM technology used. For testing, the model turbine is mounted in a wind tunnel on a simple dynamometer, allowing different levels of torque to be applied and the speed of rotation to be measured, for a variety of air speeds. Students are encouraged to plot dimensionless performance curves of power coefficient against blade-tip-speed ratio. Using these figures, they can then predict the performance of a full-size rotor with similar geometry.

KEYWORDS

Aerofoil, airfoil, additive manufacture, wind turbine.

INTRODUCTION

Design-build-test projects have formed an important part of the curriculum in all years of undergraduate programmes in the Engineering Department at Lancaster University ever since the foundation of the department in the late 1960s [1]. All of these programmes are grounded in engineering science, but the philosophy from the outset has been that graduates should be practised in applying this science fruitfully to real engineering problems. Inevitably, such real problems are never fully defined, and do not have unique 'right' solutions: the students have to learn to make engineering decisions on the basis of incomplete information. They also need to realise that costs and the need to conserve resources are important considerations in any engineering project. Accordingly, many of the design-build-test projects include economic considerations of some aspects.

A project undertaken by most students in first year is to work in small teams to design, build and test a model wind turbine. The maximum diameter is 200 mm, so that the turbines can readily be tested in a small wind tunnel; but within this constraint there is much scope for students to make choices. Being mostly fresh out of school, the students generally find making decisions on the basis of incomplete information quite uncomfortable. However, the need to do this occurs often in real engineering situations (and indeed in life), so the ability and confidence to make such decisions is an important and useful skill.

This philosophy is very much in line with the CDIO approach, as set out for example by Crawley *et al* [2] and Hugo & Goodhew [3]. However, this project, being at first-year undergraduate level, is relatively constrained: the diameter of the model turbine is restricted and the test set-up is fixed, so the freedom to conceive different turbine designs is somewhat limited. What is more, there has never been any intention to operate the turbine outside the laboratory, although students are encouraged to use the test results from the model as the basis for a prediction of the performance of a full-size turbine of similar geometrical design.

REVIEW OF PREVIOUS WORK

Making aerofoils by additive manufacture

There is a growing body of literature reporting the manufacture of lightly-loaded aerofoils by AM methods.

In the USA Stamper and Dekker fabricated a wing from ABS (Acrylonitrile Butadiene Styrene) material in order to compare it with an aluminium one of the same cross-section [4]. Because the ABS wing was built up in layers, it was rough compared to the aluminium one and its performance was not as good. However, once its surface had been smoothed, the lift and drag curves were found to approach those for the aluminium wing.

In Germany, AM methods have been used to fabricate aerofoils with embedded sensors, to form aerodynamic components of racing cars [5]. In this case, AM was used because it readily allowed the aerofoil profile to be altered to incorporate the sensors - but it is clear that the aerofoil functioned well even though it was made by a layer-lamination method, and as such its surface will have been relatively rough.

At Lancaster University, a model of a vertical-axis tidal power device has been manufactured, based on a multi-element aerofoil profile [6]. In this case the multi-element profile was optimised using CFD, taking into account the very different Reynolds number value for tidal devices from the more familiar NACA aerospace geometries. The profiles were fabricated using the stereolithography AM technology, with pressure tappings designed into the profiles and incorporated at the outset. The final multi-element device was tested in a water flume in the Engineering Department's laboratory.

CDIO projects based around aerofoils

At a number of universities and colleges, aerofoils have played a significant role in CDIO design-build-test projects.

In the Department of Aeronautics and Astronautics at MIT, groups of students worked to design and build at full scale the aerofoil rear wing of a racing car with its supports, using a CNC foam cutter [7]. The resulting wing was then tested in the wind tunnel to measure the lift and drag forces. This work was aimed to support the learning objectives of the CDIO initiative, as well as using up-to-date technology including AM. Student feedback was firmly positive.

At Newcastle University, UK, second-year students taking Engineering Design undertake team projects to design and build a wind turbine from a fairly free choice of components [8]. Learning is open-ended. Lectures are given by staff in an impromptu manner in response to students' requests. High levels of student satisfaction are reported.

In Portugal, at Instituto Superior de Engenharia do Porto, first-year engineering students work in teams on a CDIO project to build a vertical-axis wind turbine, mainly from parts 'from the junkyard' and also by adapting suitable rotating electrical machines [9]. Surveyed after this experience, the students felt that projects of this kind were important 'for better learning outcomes and collaborative multidisciplinary issues'.

The student project at Lancaster University has evolved from one where the blades were made completely by hand. In the first stage of evolution, the blades were fabricated by AM and

mounted on radial rods retained in a brass hub [10]. This had the drawback that the blade angle could easily be set up incorrectly. In the present arrangement, the blades are built with their end fittings incorporated, so that the blade angle is fixed.

DESIGNING AND BUILDING THE MODEL WIND TURBINE

For the design and implementation of their model wind turbine, students at Lancaster University work in groups of two or three. The time allocated for the exercise totals 15 hours, consisting of five three-hour practical sessions over a period of five weeks, together with a small number of associated lectures. In this fairly concentrated period a number of useful learning outcomes are achieved.

Power available in a moving fluid - Betz limit

The final part of the practical work undertaken by the students, once they have completed the manufacture and assembly of their model wind turbine, is to assess its performance by testing in the wind tunnel, and to compare the power captured with the theoretical maximum. The students therefore need to be able to estimate how much power is available in the wind that passes through an area A perpendicular to the wind direction.

This entails calculating the kinetic energy in the air passing through the area A per unit time, and then appreciating that it is impossible to capture all of this energy, otherwise the air would be stationary behind the turbine. Clearly the air must move away to make way for air following on behind.

The energy E that would pass through area A in a free stream is thus

$$E = \frac{1}{2}\rho Au^3 \quad (\text{Eq 1})$$

where ρ is the density of the air, and u is the air speed. The German engineer Betz showed in 1919 that the maximum proportion of this energy that can be captured is 59% - see for example ref [11].

Tip-speed ratio

The first design decision that students need to make in their blade design is the tip-speed ratio λ of the rotor. This is the ratio of the speed of the blade tip as it rotates to the speed of the wind. Closely related to this is the decision on the number of blades in the turbine rotor.

Most modern wind turbines in Europe have three blades, and in this case the optimum tip-speed ratio is in the range 6 to 7. At a lower ratio than this, too much air passes between the blades without contributing its energy to the power capture; at a higher ratio, the wake from one blade interferes too much with the flow around the next one. In North America, two-blade rotors are common; the optimum value of λ is then as much as 9.

For work at model scale, two-blade rotors use less material and so are cheaper to make; they are also easier to balance. Most students choose to make a two-blade rotor for these reasons, although some make three-blade rotors, and those who like to challenge convention manufacture one-blade rotors with a counterbalance mass. In commercial practice, there may be good reasons to choose any one of these: a low-speed rotor when high torque is needed, e.g. to drive a reciprocating piston pump directly; a three-blade medium-speed rotor because they avoid most of the problems of periodically-varying loads and are pleasing aesthetically; or a two- or one-blade high-speed rotor to minimise the cost of the blades and step-up gearbox that is needed to drive the generator.

Angle of attack, relative velocities, and the need to twist the turbine blades

The blades of horizontal-axis wind turbines have aerofoil profile. The students can use any aerofoil shape, provided they document the selection in their report. However, they are advised to base their aerofoils on the NACA4 standard, developed by the US National Advisory Committee for Aeronautics [12]. Here the students can choose values such as the chord length, the blade thickness, and the camber (i.e. the curvature of the centre-line of the blade). They can then use a simulator to check the performance of their chosen aerofoil, and alter the values in pursuit of improved performance if they wish.

For each aerofoil profile, the lift force increases with the angle of attack up to a certain point. Beyond this, the lift suddenly drops as the flow stalls, separating from the upper surface of the wing shape. Some advanced aerofoil shapes allow quite large incidence angles before the onset of stall - but the loss of lift when stall occurs can be quite sudden, so these advanced shapes are less forgiving than the simpler shapes.

By being involved in these decisions, students learn that compromise is inevitable in engineering design.

Due to rotation of the turbine, the speed of motion of the blade at radius R is $R\omega$, where ω is the angular velocity. The wind speed is U , in the axial direction. The velocity triangle for the blade at this radius (Figure 1) shows that the direction ϕ of the velocity w of the air relative to the blade depends on the ratio of U to $R\omega$; thus, it varies with the radius R . To maintain a constant angle of incidence ϕ of the air on the blade along its whole length, the blade must therefore be twisted.

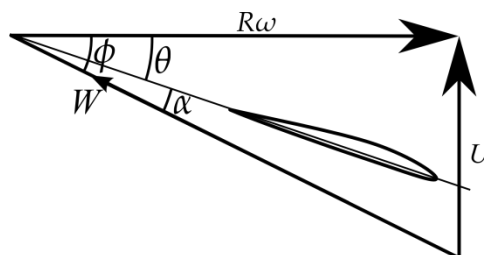


Figure 1: Velocity triangle at radius R

Manufacturing considerations

The FDM technology can produce accurate shapes in the two-dimensional horizontal layers (slices), but in the vertical direction the part produced is discretised into layers of finite thickness, and ridges appear at the edges of the layers (known as stair-stepping). If a blade is built laid horizontally, it will have ridges running along the length of the blade, perpendicular to the air flow, and this is likely to compromise the performance of the aerofoil [4]. If the blade is built standing vertically, the ridges will be parallel to the air flow, which should be more acceptable. Furthermore, a blade built in the vertical orientation requires less support structure (required to support overhanging structures or geometric features) than one built horizontally. However, the horizontally-built blade will have greater strength in the longitudinal direction, which is the direction of the bending stresses. Figure 2 shows blades as they come from the FDM machine, with the support structure still in place.

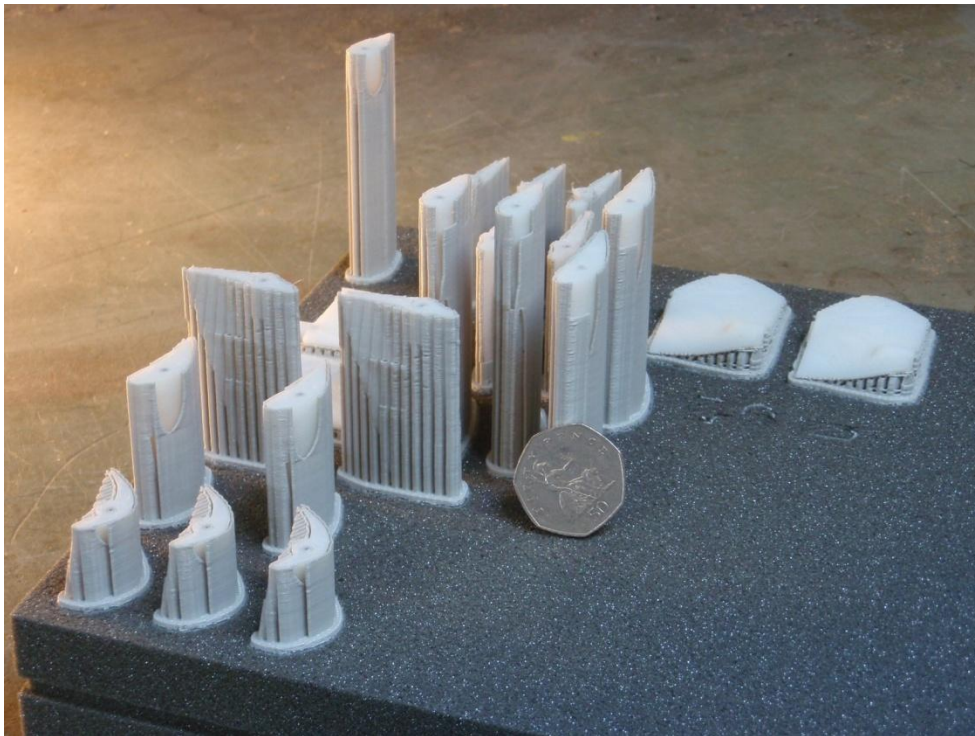


Figure 2. A bank of just-built model turbine blades on their platen, with the support structure still in place

The cost of the ABS material used in the FDM technology is significant. As an incentive to students to be economical with the material, the marking scheme for the project includes a sliding scale for marks to be added (or subtracted) if the blades are particularly light (or heavy).

The correct aerofoil shape has a thin trailing edge, tapering away theoretically to nothing. However, the FDM AM process has some difficulty in reproducing such fine features as this, a drawback of the extrusion/deposition process - it yields only a weak raggy edge. To overcome

this, students are asked to thicken the trailing edge in the CAD model before committing to manufacture; they then have to remove this additional material thickness later in post-processing operations, including a combination of filing and abrasive finishing using sandpapering.

Finishing and balancing

To achieve a smooth surface on the blades and hence low drag, the students are recommended to fill the surface with a two-part car-body filler, before sanding it to a smooth finish. The students have to take care not to sand too vigorously, in order to preserve the geometry of the aerofoil.

Before testing the rotor in the wind tunnel, it must be static balanced, using a dummy shaft and knife-edges. For the purposes of manufacturing the geometries required in this project, the AM process is generally accurately repeatable, so usually the rotors are very nearly in balance, and all that is required is to remove a little material from the tip of the blade on the heavy side.

A finished rotor is shown in Figure 3.

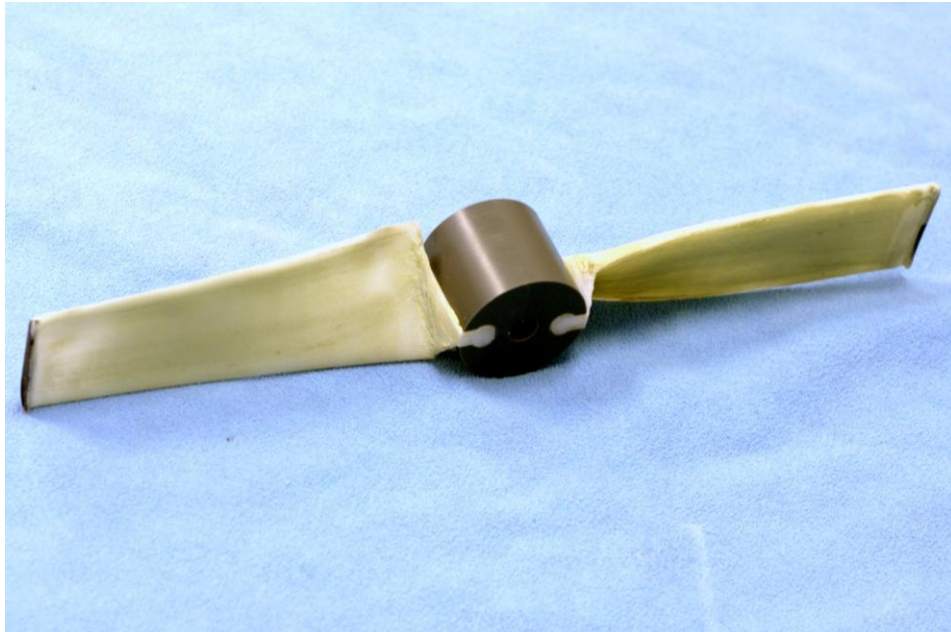


Figure 3. A finished model wind turbine ready for testing

Testing and reporting

For testing, the model rotor is mounted on a dynamometer in a small wind tunnel. Torque is applied by a simple Prony (friction) brake. The rotor speed is measured using a non-contact instrument such as an optical tachometer or a Hall effect sensor.

The students are advised to plot dimensionless performance curves, of the power coefficient against the tip-speed ratio. The power coefficient is the ratio of the power produced by the turbine to the power available in the wind (Eq 1). For a given rotor, these curves should be approximately the same, regardless of the air speed. The students can use these results to predict the performance of a full-size wind turbine with a geometrically-similar rotor.

Each student presents an individual report, containing a record of the experimental measurements and calculations, the performance curves, calculation of the size of rotor needed to generate 1 kW in steady wind of standard speed.

CONCLUSIONS: Learning outcomes relevant to CDIO syllabus

From this design-build-test experience on a model wind turbine, a range of learning outcomes are achieved.

- Students learn about the behaviour of fluid passing around an aerofoil, including the generation of lift and drag. Because the wind turbine rotor is itself rotating, the students learn about relative velocities, how the angle of the relative velocity varies with the radius, and that the blade has to be twisted to maintain constant angle of attack and hence good lift performance all along the blade. In designing their model turbine, they use their early understanding of fluid flow, including the boundary layer and its attachment to or detachment from the surface of the aerofoil shape, and the relationship between the force on the foil and the change of momentum of the air flowing around it. These are important ideas in mechanics, and are part of core engineering knowledge for all engineers [CDIO syllabus 1.2]
- The students are able to choose the number of blades on the rotor in order to give high-torque or high-speed turbine performance, and they have the opportunity to experience this in practice when they test their own rotor.
- As the blades are fabricated using an AM technique, students are able to achieve quite accurate aerofoil profiles and profile angles along the blade. However, for best performance they need to address any surface imperfections generated as a result of the AM process, typically through manual finishing methods.
- When testing the rotor, the students learn about the use of the wind tunnel, including the instrumentation. The testing of the turbine, using a simple dynamometer and a wind tunnel, involves a number of simple instruments. Students need to make allowance for common problems such as friction in the dynamometer bearings, and for experimental errors in determining the air speed in the tunnel from readings on an inclined manometer. All of this introduces engineering reasoning through experimentation [CDIO syllabus 2.1 and 2.2]
- Students work in teams of two or three, and because there is some time pressure they quickly find that they need to divide tasks between them in an efficient and effective way so that the overall aim can be achieved in the time available [CDIO syllabus 3.1]
- In this exercise, students learn of the advantages of presenting their measured results in terms of dimensionless ratios - the power coefficient and the tip-speed ratio - and how

these dimensionless results can be used to predict the performance of a wind turbine of a different scale. In the final part of their individual report, they are required to use the dimensionless power coefficient and tip-speed ratio to predict the performance of a full-scale wind turbine of the same geometric shape. This is a powerful technique that is often not well understood, even by professionals, and it is good to introduce it at this early stage of the undergraduate course. [CDIO syllabus 1.2]

This wind turbine exercise packs a great deal of educational value into a relatively short and economical project - and usually students find it enjoyable.

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THE USE OF DESIGN THINKING IN C-D-I-O PROJECTS

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ABSTRACT

For students taking the “Design and Innovation Project” module at the Singapore Polytechnic, it has been observed that the most difficult step in the C-D-I-O process is the first step - “conceive”. The “Design Thinking” method emphasizes “deep user understanding” through detailed survey / observation of the end users, and subsequent analysis of the data collected. Can the Design Thinking method help students in the “conceive” step? This paper describes a “pilot/trial run” to use the Design Thinking method in conceiving project ideas. It also outlines the limitations / constraints of the method.

KEYWORDS

Design thinking, empathy, ideation.

AN OVERVIEW

Ever since the C-D-I-O approach has been adopted as the teaching methodology, students of the second year “Design and Innovation Project” module at the Singapore Polytechnic, School of EEE, have been able to conceive, design and implement a wide variety of project ideas, based on a micro-controller.

It has been observed that the most “painful” step in the C-D-I-O process is the first step – “conceive”. Amongst the problems faced by students during the “conceive” phase were: 1. Time constraint. 2. Lack of a structured approach to idea generation and selection. 3. Lack of life experience to make judgment on the usefulness of an idea.

The Design Thinking method emphasizes “deep user understanding”, through detailed survey/observation of users and subsequent analysis of the data collected. Can the Design Thinking method be used in the “conceive” step?

A multi-disciplinary group of students went through a “pilot run” to use the Design Thinking method to understand end users’ needs, to generate and select project ideas. As students could see the relevance of their projects, the projects were continued as their final year projects.

This paper describes how Design Thinking can be used to help students develop good user understanding, so that good project ideas can be conceived. It also highlights some of the constraints in the use of Design Thinking in C-D-I-O projects.

HOW IS THE “DESIGN AND INNOVATION PROJECT” MODULE TAUGHT AT SINGAPORE POLY?

The module “Design and Innovation Project” is taught to second year students in three diploma courses (Diploma in Electrical & Electronic Engineering, Diploma in Computer Engineering and Diploma in Electronic & Communication Engineering) in Singapore Polytechnic. ^[1]

The students are given 30 hours over 15 weeks to work on a C-D-I-O project, with the requirement that the project must be a microcontroller application. Each class of (approximately 20) students will first be divided into teams of 4 or 5 students.

The students will next identify their areas of interest e.g. helping the elderly or handicapped or solar energy applications. The lecturer will then explain the importance of doing a survey to find out what the user needs, instead of simply assuming. The students will also be taught some techniques to carry out a survey e.g. interview in pairs (one asking questions, the other taking notes), questions should be open ended (not yes/no answer) etc.

The actual act of carrying out the survey will be left to the students. In other words, the project team will have to arrange a time outside the curriculum hours to interview a target user group to find out what they need.

The students will also be asked to research the “product landscape” – what products or services are already in the market to serve the needs identified in the survey? How can “blue ocean strategy” be used to outdo the competitors?

With some knowledge of both the demand and supply sides, the students will next brainstorm to come up with a viable project idea, before presenting to the lecturer and fellow classmates. The idea will often be presented with a “concept sketch” (see Figure 1) to illustrate how it will look like at the end. The students will also present a “user journey” to show how a typical user will use the end product.

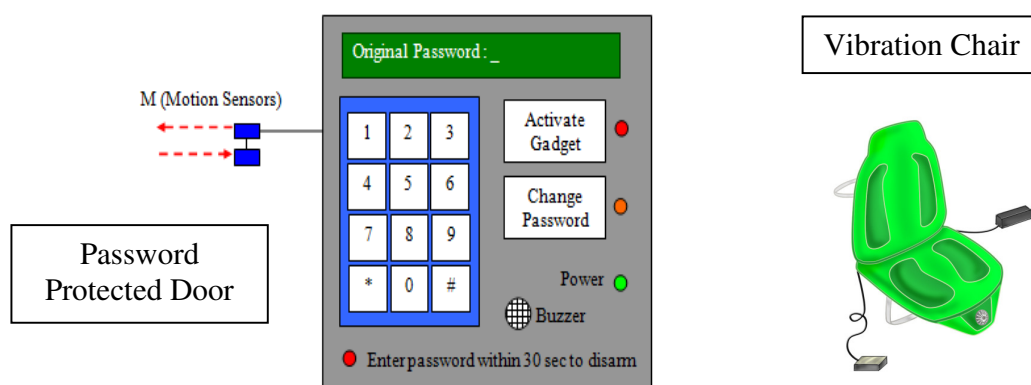


Figure 1. Concept sketches

After this “C” (“conceive”) stage, students will move on to the “D” (“design”) stage, where engineering students will be back to their “comfort zone”, drawing block diagram and circuit diagrams for their hardware design and flowchart for their software design. At this point, they will also be asked to work out an “implementation plan”, so that a simple, working prototype can be created over the next 5 or 6 weeks, during the “I” (“implement”) stage.

Within the limited time available for this project, a typical class of 5 teams may produce these:

- A “password protected door” – a correct password must be keyed in via the keypad for the solenoid (which “locks” the door) to be de-energised.
- An “alarm clock” – when the alarm buzzes, four LED’s will light up in a random sequence, and the sleepy fellow must press four buttons in the same sequence to switch the alarm off.
- A “toilet cubicle occupancy indicator” – red LED means a cubicle is occupied, green LED means vacant, and the total number of available cubicles is indicated outside the washroom for the convenience of the users.
- A “blind man stick” – an obstacle detection / warning gadget for the visually handicapped.
- A “vibration chair” – when seated on for some time, will shake to remind the user not to be desk-bound for too long.

DIFFICULTY IN “C” (CONCEIVING)

It has been observed that the most “painful” step in the C-D-I-O process is the first step – “conceive”. Just how do 18/19 years old students, with limited life experiences, come up with ideas that are technically feasible and yet, are “wanted” or “needed” by others? It is not easy to make judgment on the usefulness of an idea. Amongst the other problems faced by students during the “conceive” phase are: time constraint and the lack of a structured approach to idea generation and selection.

The time constraint comes about because there are only a total of 30 hours over 15 weeks to work on the C-D-I-O project, with a large portion (20+ hours) needed for “I” (Implementation). Implementation involves hardware fabrication, microcontroller programming, interfacing and troubleshooting. That leaves very little time for “C” (Conceive) and “D” (Design).

It is also not easy to guide a few groups of students in a class through user study, idea generation and selection mainly because the students have very different areas of interest – a group may be interested to help the elderly while another group may be interested to help road users etc. As a result, the act of carrying out the user survey is largely left to the students.

That leads to the question: Can the Design Thinking method be used in the “conceive” step?

WHAT IS DESIGN THINKING?

What actually is “Design Thinking”? If you Google this term, chances are you end up seeing Stanford’s D School or Tim Brown etc.

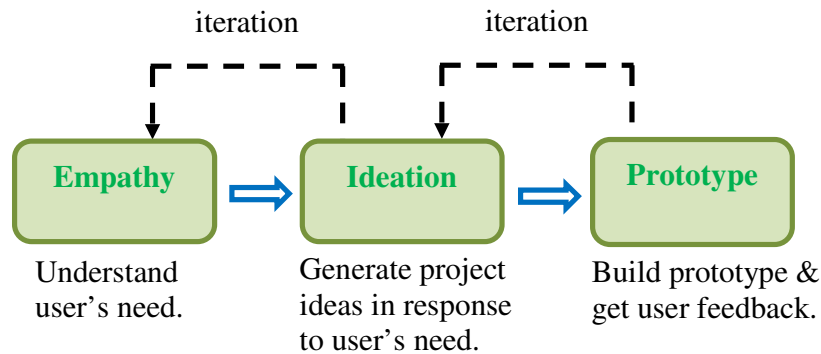
Design Thinking transcends disciplinary boundaries and adopts a fluid process to address a wide range of problems and issues. While there is no single definition for it, a useful starting point is the description below:

“Design thinking can be described as a discipline that uses the designer’s sensibility and methods to match people’s needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity.” – Tim Brown CEO, IDEO [2]

It is a methodology for practical, creative resolution of problems or issues. It is the essential ability to combine empathy, creativity and rationality to meet user needs.

Design Thinking is a creative process based around the "building up" of ideas. There are no judgments early on in Design Thinking. This encourages maximum input and participation in the ideation and prototype phases. [3], [4], [5]

In Singapore Polytechnic, the (simplified) Design Thinking flow (see Figure 2) has the following key steps: Empathy, Ideation & Prototype. It emphasizes “deep user understanding”, through detailed survey/observation of users and subsequent analysis of the data collected.



Simplified Design Thinking flow

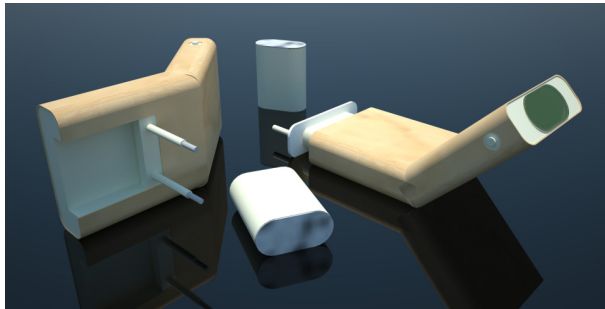
Figure 2. Steps in Design Thinking

In the Empathy step, the team of designers (or engineers) makes an effort to understand the user needs i.e. what kind of product or service the user really requires. This is done through a number of techniques such as survey and observation.

Once the user requirements are well understood, the team moves on to the Ideation step to brainstorm and propose possible solutions that may help to solve the user's problem. Concept sketches can be drawn to capture the ideas.

Often the proposed solutions result in “low resolution prototypes” (so called “quick and dirty prototypes”) which are then presented to the users for comments. The quick prototypes (see Figure 3) allow unsuitable ideas to fail early, when the cost of failure is still low.

The prototypes do not have to be functional at this point in time: communicative prototype (such as one that is made of cardboard) that shows how the end product or service is to be used will suffice. It can even be in the form of a video, a skit, a comic strip or simply a good sketch.



“Form prototype”
made of plastic – a
form prototype gives
an idea how the end
product will look
like, without being
functional.

Figure 3. Quick prototype

The user feedback is used to refine the proposed solution. After this, the team moves on to build a functional prototype, before the end users are once again engaged to test-drive the product or service.

The flow is an iterative process. For instance, if (during “Ideation”) the team discovers that they do not really have sufficient understanding of the user requirements to propose a good solution, they may have to repeat the “Empathy” studies.

As described above, the simplified Design Thinking flow contributes to the C & D portions of a C-D-I-O project (see Figure 4).

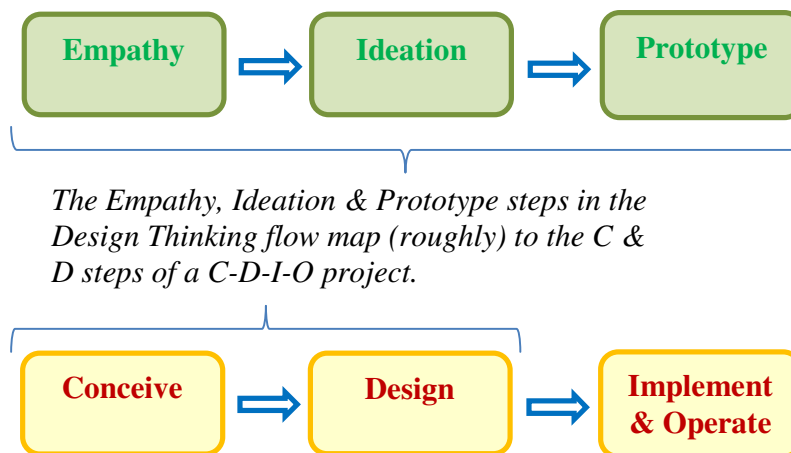


Figure 4. Design Thinking in C-D-I-O

HOW WAS DESIGN THINKING USED TO HELP STUDENTS CONCEIVE GOOD PROJECT IDEAS?

In September 2009, 80 students (and a number of lecturers) from three different schools of Singapore Poly (School of Electrical & Electronic Engineering, School of Mechanical & Aeronautical Engineering and School of Design) came together for a 4-day Design Thinking Workshop. Forty “senior citizens” (aged 50 and above) were also invited as users / co-designers. The theme of the workshop was “Dream Home”. The purpose of this workshop was

to allow students from different disciplines to come together and use the “Design Thinking” method to solve real problems.

The 80 students (and 40 senior citizens) formed a total of 20 Multi-disciplinary project teams, each with 4 students (and 2 senior citizens and a lecturer as facilitator).

During the “Empathy” step, the following activities were carried out:

- The end users created “mood boards” (with pictures and words cut out from magazines pasted onto cardboards) to express their ideas of a dream home.
- The project teams went to the homes of the senior citizens to observe their living environment.
- The project teams interviewed other end users e.g. senior citizens at places where old people like to hang out.

After all the “mood boarding”, interviews and observation, the project teams started the “Ideation” step. They analysed the data collected (observation, comments, insights etc.) and brainstormed to produce project ideas that could address the issues raised by the senior citizens in search of a “Dream Home”. The ideas were captured as concept sketches, comic strips, videos, quick cardboard (i.e. “non-functional”) prototypes and presented for critique.

After the 4-day workshop, the students and lecturers from the 3 schools continued to meet for 4 hours every week (over 2 months) to refine the project ideas.

One thing that stood out during the process was: The Design Thinking methodology does not aim for fast convergence – i.e. it does not try to arrive at “the solution” quickly. It encourages taking a step back every now and then, and asking “is that what the user really wants?”

After the 2-months of idea refinement, the students and lecturers from the 2 engineering schools regrouped themselves into 6 project teams to work on functional prototypes of 6 selected ideas over a further 2 months:

1. A horizontal fridge - that allows the elderly to take the stuff in the fridge without bending, as too much bending gives the elderly a back problem.
2. An item finder – that helps the (often forgetful) elderly to locate lost items in the house.
3. A family mirror – which lets the family members leave video messages for others, before leaving home.
4. A hassle free garden – that taps solar power and allows programmed regular watering of the plants.
5. A “dust monster” – that allows users to play a game of PACMAN while mopping the floor. Perhaps this will allow the elderly to pass the daily chore of mopping to his grandchild?
6. A set of “family together mugs” – that light up more LED’s when more family members dine together. This serves to subtly remind the family members the importance of having meals together.

As the engineering students could see the relevance of their project ideas, these second year projects were carried on as final (third) year projects.

Back to the question: how was Design Thinking used to help students conceive better project ideas?

The following table summarises the qualitative differences between the projects conceived with and without using Design Thinking:

Table 1
Qualitative differences between projects conceived with and without Design Thinking

Projects conceived by “Multi-disciplinary Project / Design Thinking Workshop” students	Projects conceived by “Design & Innovation Project” students
<ul style="list-style-type: none"> • Show evidence of end user research & data analysis. • A lot of time is spent identifying the problem i.e. the “what”. There is no rush to arrive at the solution i.e. the “how”. • Details of projects arrived at after a lot of deliberation and iterations, based on the persona of an end user. • Focus is on the end user needs and concerns. • Solution to problem requires domain knowledge from other disciplines e.g. mechanical engineering. 	<ul style="list-style-type: none"> • Evidence of end user research & data analysis often lacking. • Convergence to THE problem happens too quickly. • Details of projects arrived at after a quick “brain storming” session. • Focus is often on what project the students can do in the limited time, with their limited knowledge and skills on micro-controller. • Solution to problem can be provided by electrical & electronic engineering students alone.

The following table summarises the differences between the usual “Design and Innovation Project” module and the pilot run of the “Multi-disciplinary Project / Design Thinking Workshop”:

Table 2
“Multi-disciplinary Project / Design Thinking Workshop” vs. “DnI Project” module

	Multi-disciplinary Project / Design Thinking Workshop	Design and Innovation Project
Time given for the whole project	4 full days (during the vacation) + 4 hours x 15 weeks + final year project time (9 months duration, approximately 6 hours per week).	30 hours over 15 weeks
Time given to conceive a project idea	4 full days (during the vacation) + 4 hours x 8 weeks.	4 weeks of students’ own time (i.e. not time-tabled) - students attend briefing during scheduled lessons but do the work outside classroom hours.
“Theme” for the project?	A theme such as “Dream Home” is given.	Students are free to choose their area(s) of interest.
Guidance / help during the “conceiving” step	Arrangement is made to engage the target end users. Each team has a lecturer as facilitator to provide guidance.	Only briefing given. Students have to plan how their interview / observation etc. is to be carried out.
Nature of project team	Each project team is multidisciplinary in nature, consisting of a few EEE, a few mechanical engineering and a few design students.	Each project team consists of 4 or 5 EEE students.

It can be seen from the table that a lot more time was given to the Multi-disciplinary Project / Design Thinking students to understand the users and their needs.

Arrangements were also made for the students to engage the end users and to make the logistics possible, students were asked to work on a single theme “Dream Home”.

The lecturers (facilitators) worked closely with and guided the students through the interviews / observations and subsequent data analysis.

The fact that each team is multidisciplinary in nature also helped students to “dream big” as technical issues became less of a constraint – if a EEE student cannot fabricate a structure, their team mate from the other school will be able to help.

As a result of these differences (extended empathy study to understand users + facilitation/guidance + multi-disciplinary team), the ideas conceived using Design Thinking better address the end users’ needs, as outlined in Table 1.

SOME CONSTRAINTS, ISSUES AND FINAL THOUGHTS

As is evident from the discussion above, the use of Design Thinking in conceiving good project ideas comes with a set of constraints.

1. Time constraint – It is sometimes possible to persuade students to forfeit a few days of their vacation to come back to school and do “user empathy study” for their projects. These students also spend additional few hours per week over a number of weeks on their C-D-I-O project. Often, additional time must be allocated in the curriculum hours for students to carry out user study.
2. Logistic arrangement required for students/staff from different schools to work together. They must have common time-tabled hours for C-D-I-O project. The lecturers must be time-tabled likewise. There must be a venue large enough to house so many students.
3. Facilitation needed, such as arrangement for students to engage / interview / observe end users. Such arrangement is only possible when students work on the same project “theme”, for instance, “Dream Home for the 50+”.
4. It was also difficult to get the same group of end users (50+) to stay with the student project teams throughout the project. So, the prototypes created could only be shown to other end users for comments and refinement.

The “pilot run” of the Multi-disciplinary Project / Design Thinking Workshop, although a success in terms of learning experience, proved to be very resource-intensive – in terms of time, logistics and facilitation required. It would not be easy to allow a large number of students to go through the same experience.

To allow more students to benefit from Design Thinking in their C-D-I-O projects, Singapore Poly has started developing a comprehensive “Design Thinking Tool Kit” – a collection of common Empathy / Ideation / Prototyping tools that the lecturers will learn and coach the students to use in their projects. Such tools allow more lecturers to become acquainted with Design Thinking methodology quickly, and to facilitate students’ project work in various settings.

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Biographical Information

Chong Siew Ping has been a lecturer with Singapore Polytechnic since 1991. He graduated from National University of Singapore (NUS) with honours degree in Electrical Engineering and later pursued his part-time Master of Science degree (in Electrical Engineering) in the same university. His professional interests are embedded system design, logic circuit design & FPGA (Field Programmable Gate Array)-based design. He was part of a team which developed & pilot ran the module Design & Innovation Project, which allows second year students from the School of EEE (Singapore Poly) to go through the C-D-I-O process.

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GRADUATE AND PH.D. COURSE ON DESIGN AND MANUFACTURE OF MICRO MECHANICAL SYSTEMS

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ABSTRACT

Micro mechanical components play an increasing role in micro systems with product dimensions ranging from micrometers to millimetres. The use of metals, polymers and ceramics for miniature components requires product development methods as well as specific manufacturing technologies. Indeed it is now well known that micro/nanotechnology is not only a matter of downscaling applications and methods from the macro scale, and therefore an in-depth understanding and knowledge of product and process characteristics at this scale is necessary. Based on this challenge, a new course was developed at the Department of Mechanical Engineering at the Technical University of Denmark. This paper describes the framework of the course that has been applied both at graduate and Ph.D. level. The current structure of the course as well as the pedagogical approach and some examples of final projects will be presented. Moreover, the transformation of the traditional semester structure (13 weeks and 3 weeks project) into a 2 weeks PhD summer school is discussed.

KEYWORDS

Micro manufacturing, multidisciplinary teaching, theoretical and practical balance

CONTEXT: SPECIFICITIES OF MICRO PRODUCT DEVELOPMENT

The design and manufacture of mechanical micro and nano products (or systems) is still considered to be a very difficult and challenging task. For one, the manufacturing technologies used to produce them are either emerging or pushed to the limits of their capabilities [1]. In addition to that, the physical working principles and design solutions are often not in the same area as common engineering, taking roots in for instance biology and fundamental physics rather than in mechanics. Moreover, little of this knowledge corpus is stabilized and available outside of the research and development context. The very nature of micro products induce a collaborative and multidisciplinary way of working, such as in MEMS design [2]. All of these concepts require both specific research and teaching activities.

One major issue is the multidisciplinary community involved in the development process of those micro / nano scaled products. It creates communication problems and an interlaced network of knowledge-related topics. Indeed, manufacturing knowledge is reckoned to be extensively used all along the design process, although knowledge in this field is neither stable nor mature. Another major issue in the development of micro products is their integration with the external world or the system, and how to make them fit and interact inside macro scale products. Packaging for micro products not only includes electric

connections and protection of the systems (as in VLSI chips), but the physical interface is also required to achieve specific functionalities, e.g. fluidic couplings [3].

Old design premises state that design is independent of the technologies or of the product involved. They also reckon that a product development process has to include analysis of the design problem, synthesis of possible solutions and evaluation of design proposals all in a traditional problem solving approach. It has been shown both in industrial practices and through research in design methodology that such premises are not only outdated but also most often can result in bad design. The products and the technologies are all part of the product development scheme and should be given attention throughout the development process. Moreover the designers represent a complete part of the design process where creativity and difficult-to-model activities abound. Design as a discipline should cover these three aspects of product development [4].

The research conducted at the authors' group cover products, methods and manufacturing processes: On the products side close collaboration is carried out with industrial companies requiring mechanical solutions on the micro scale. The sectors include medical, hearing aids, electronics etc. and an example is an interactive optical display for Bang & Olufsen [5]. MID technologies are also part of the products investigated.

From a methodological point of view, studies comparing a product driven approach and a technology push approach in the design of for example a superhydrophobic surface using a biomimetic approach [6] are conducted. They include metrology and surface engineering issues [7]. The inclusion of life-cycle assessment in the development of micro technologies is also part of the line of research.

On the manufacturing process side, replication techniques for mass production such as micro injection moulding [8,9] or micro metal forming [10] are investigated. These technologies require tooling and therefore various manufacturing technologies are investigated: micro milling, laser processing, micro EDM, electrochemical deposition etc. [11].

As previously exposed, design of such products and using such processes can only be made viable in a very collaborative environment. A collaborative culture is needed to create the framework to work in. Indeed, more and more industries adopt multidisciplinary and concurrent engineering based methods to achieve innovation and product development in accordance with the classical triptych "cost-quality-delay" dilemma, especially with the current fast time to market which is required. Such an approach has been called the PMP approach, Product-Method-Process [12], at the University of the authors, as illustrated fig.1.

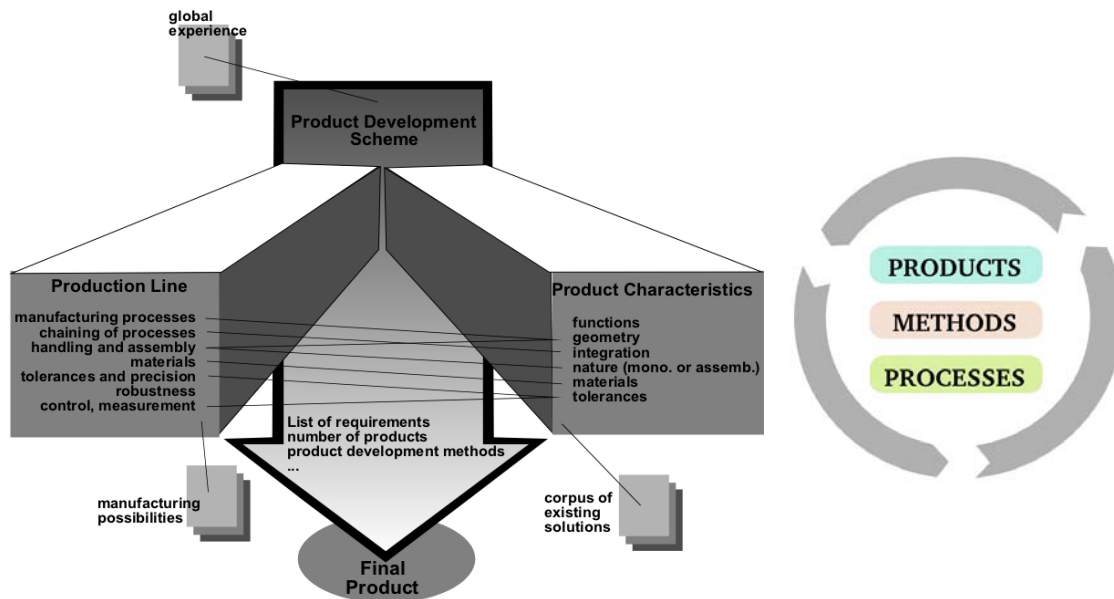


Fig.1. Representation of a product development scheme, product and process are developed concurrently and are tightly linked, as also shown in the PMP circle.

As often stated, real-world practices and education are feeding each others. Indeed students are the company employees of tomorrow and bring new methods and tools (e.g. the adoption of CAD/CAM systems in the history of automated production) to the industry. These new methods and tools are transformed by industrial usage and have to get back inside the classrooms. Therefore it is crucial to have not only product development courses that focus on all the multidisciplinary aspects of engineering design, but also which take into account the specificities of the micro/nano scale products and industrial practise.

PEDAGOGICAL CONSIDERATIONS

Numerous studies have been made about pedagogy and teaching. Some of them contain axioms or principles to enhance the student ways of learning [13]. Following such principles can help tailoring courses once scientific aims and objectives have been set. Important elements include:

1. Interest and explanation: It is very important not to make the lesson drudge but pleasant to follow, create it enjoyable to work at it. The beginning of the course should clearly show the benefits of the outcome.
2. Concern and respect for students and student learning: As Eble [14] states: "knowledge suffers no loss when it is shared", the availability from the teachers for consultation about academic work has to be provided. For example, in DTU, a website is available as a file sharing and forum to enhance discussion between teachers and students. Moreover appropriate assessment and feedback are necessary for the students to acknowledge their progresses. Evaluation and self evaluation is an essential issue.
3. Clear goals and intellectual challenges: A balance between freedom and discipline (interesting challenges are the core of the "romantic" aspect of learning) has to be found in order to keep the overall spirit of the course high and propitious for learning. Experience showed that colourful examples along with hardcore scientific matters keep the attention of students, as well as real-life industrial cases.
4. Independence, control and active engagement: Students have to practice the art of inquiry by themselves. Indeed independence ensures the individuality of some part of the learning because each student is different, although teaching cannot be tailored

for each one of the student. Moreover the grading system in DTU allows a significant value of independence, along with actual results to exams and exercises. Besides, collaborative learning and competitive (or individualistic) learning have to be among the practices of students. The course should provide both ways of learning.

5. Learning from students: Feedback from the students is essential to improve the course and keep it to a high level of education.

Surely the taught topic is of tremendous importance and brings many specific issues in the way to teaching. In the case of the described set of courses a full list of learning objectives will be given in the next paragraph.

However, teaching about design methods is somehow different than teaching specifically about manufacturing technologies or working principles for engineering solutions. For instance, there is no official generic theory about design. It is therefore difficult to lecture about how to design, as in a set of systematic rules and actions to perform that will ensure a good design. The authors think, along with Schon [15] and Prudhomme et al [16], that part of the education of designers should come from reflective practices where one (students but also engineers in the case of an industrial workshop) built experience and knowledge in a contextual way. Students learn to become more aware of how they know what they know, as well as what they have learned. That doesn't mean that design methods such as the axiomatic design [17] or the systematic top-down design [18] should be turned down, they are part of the background and the culture of designers. Especially in the field of micro technologies the Design for Manufacturing is a key point to be understood and applied by the students. Such methods provide a framework in which to work and raise relevant questions. It is fundamental to have a broad knowledge in terms of methods and also enough distance to know how to choose among them, their strengths and weak points. During the course the students will have lectures on design methods, on methodology and they will be involved in a reflective analysis of their own design practices in a design role-playing game: the Delta Design game [19]. We also believe that it is important to put product development in relation to the global economy and world development. It is not the purpose of this course to give extended knowledge about history or economics, a historical point of view is nevertheless given about design. Indeed it is important to understand how design evolved from being a one man craftsmanship to a multinational concurrent engineering team collaborative work.

The application of CDIO principles to this particular context seems intuitively straightforward. Nevertheless, the practical implementation of conceive-design-implement-operate into this context has involved the establishment of an industrial-like learning environment and the definition of learning objectives that reflect a holistic teaching approach (technical skills, personal skills, social and collaborative skills).The content of the course(s) is built around Design-Build experiences and a natural progression has been implemented in the course(s). The course(s) are constructed as a full blown engineering design process with "just in time" information given to or constructed by the students as they move along.

DESCRIPTION OF THE SET OF COURSES

Teaching is of course a matter of telling (or transmission) but it also consists of organizing student activities in order to make learning possible and with the best output possible. Therefore clear aims and objectives, and careful scheduling have to be defined. Aims are general statements of educational intents, whereas objectives are more specific and concrete statements of what students are expected to learn in single lectures. Also it is important to adapt from the students background and expectations, reasonably.

The course set encompasses two separate courses titled: "Introduction to micro mechanical system design and manufacture" (course #41742 in the DTU catalogue) and "Workshop in micro mechanical system design and manufacture" (course #41743). The first course will

give the students the necessary technical competences to actually be able to be successful in the second course.

The courses are designed for both graduate students and PhD students. By micro mechanical systems it is meant complex products, systems which are multi-material but not focusing on silicon (MEMS are not treated into details during the course even if an introduction to silicon manufacturing is given). The courses are as previously stated closely related to the industry, through examples, lectures, and excursions... Besides, the second one, more applied, is based on an industry-like project in order to give students an overview of a complete product development process. The students indeed acquire the necessary knowledge to achieve the complete product development and do actual manufacturing and testing of a specimen. That can be called process chain prototyping rather than simply product prototyping as the project is done within a real mass production frame and actual pre-series like production is realized. Examples of students realizations are given below.

The main aim of the course set is to build a new knowledge corpus applied to micro scale (most of the students already have some manufacturing or mechanical engineering basic knowledge) and develop new skills, including projects and teamwork. This has already been studied both in macro scale mechanical design and in pedagogical science, as previously discussed. Our teaching choices have clearly been focused towards multidisciplinary. Students should understand the "real" nature of design activities, with collaborative phases and develop skills and competencies in various manufacturing technologies. The course plan is innovative in that it focuses equally on methods, various manufacturing techniques and specific micro mechanical systems issues from the product functionalities side.

In terms of learning objectives, after the described courses the students would be able to:

- | | |
|--|---|
| <p style="text-align: center;"><u>41742</u></p> <ul style="list-style-type: none"> • Evaluate the effect of miniaturisation on every aspect of product development • Propose coherent complex micro manufacturing process chains adapted to specific micro components • Evaluate quantitatively output and principle characteristics of single micro manufacturing processes • Evaluate product characteristics and functional principles at micro scale • Apply systematic methods to create a coherent sequence of actions leading to product production • Apply a set of formal design methods based on design for manufacturing • Perform basic calculation for validation of conceptual design solutions at micro scale • Present decisions and results in reports | <p style="text-align: center;"><u>41743</u>
<u>41743</u></p> <ul style="list-style-type: none"> • Identify and derive detailed technical specifications of a micro mechanical component based on functional requirements • Propose various designs • Compare various design proposals based on technical capabilities by applying the design for manufacturing (DFM) approach • Rank and choose different designs based on criteria such as functionality and manufacturability • Evaluate selected micro manufacturing processes using experimental approaches • Verify single components and assemblies using metrological methods • Produce technical drawings for a specific micro mechanical system and related production equipment • Present decisions and results in terms of reports and presentations |
|--|---|

Lectures are designed to fall into the three PMP categories (sometimes overlapping): products, methods and manufacturing processes. As some processes are part of a bigger scheme, such as mass replication techniques, a particular attention has been given to the scheduling. For instance it was chosen to give the lecture about replication processes early in the course in order to introduce the notion of tooling, and subsequently come lectures about specific manufacturing technologies such as micro cutting, micro EDM, electroplating,

etc. These methods have been successfully known to produce good candidates for real production as stated by [11,20].

Moreover, the described technologies are available in the laboratory and are extensively used during the three weeks project of the second course. In order to have the students more proficient with the necessary technologies and ensure a successful project hands-on workshops are given at the beginning of the practical course. Indeed in order to engage the students more in the practical project work, a series of intensive tutored workshops were developed in the first half of the course. The students are therefore divided into "specialist" groups. However, these workshops only stimulate the students. They do not enable them to be totally self-operating if no prior experience with practical manufacturing issues exists; a lot of interaction with laboratory and workshop technicians is expected. The requirements to enter such a course should be set carefully. Obviously having taken the introductory course (#41742) is a very highly recommended prerequisite.

In the beginning of the practical course the Delta Design game is introduced, a role-playing game / social experiment designed to present collaborative design ways in a practical form. Reflective practices have been discussed previously and the use of Delta Design in teaching design has been studied by [16]. Moreover, in courses such as the one described which target the global product development scheme, many theoretical notions have to be conveyed, in many different fields: design, project planning, manufacturing technologies, specificities of some areas of physics (fluidics, optics, solid mechanics, etc.). That can lead to a course not very attractive to some students, most of them being more eager to have "hands on" experiences than to manipulate endless streams of equations. One of the solutions is to create project works to apply the knowledge and competencies acquired during lecturing time. And to attract students one has to design attractive projects. These projects can be falling in 3 categories:

1. useful in real life
2. in partnership with the industry
3. fun!!!

It is very important to design projects that will stay in the memory of the students because students talk to each others. Also some of these projects can be used as a display by the communication department of the University through local newspaper, etc.

#	Lectures and/or activities				
1	Introduction	Process chain overview	Product overview	Size effects modelling	
2	Correction exercise on size effects	Micro injection moulding, hot embossing and simulation for moulding			
3	Micro milling		Micro EDM		
4	Laser micro manufacturing	MEMS processes introduction	Electroforming		
5	Micro metal forming		Feedback session on report #1		
6	Micro tooling process chains (with exercise)				
7	Correction exercise on micro tooling		Metrology part I		
-					
8	Design methodology (historical perspective, collaborative design, ecoDesign)				
9	Micro glass moulding (with industrial partner)				
10	Metrology part II		Tolerancing		
11	Micro handling and assembly				
12	Industrial visit at Sonion				
13	Feedback session on reports		Preparation for final exam		
	09:00 - 10:30	10:30 - 12:00	lunch	13:00 - 15:00	15:00 - 17:00
Week #1					
Monday	intro			Lecture on collaborative design	Delta Design rules and analysis method
Tuesday	Workshops			Workshops	
Wednesday	Students' presentation on workshops				Delta Design experiment
Thursday	conceptual design	Lecture on micro fluidic theory		Conceptual design (continued)	
Friday	Detailed design + Process chain design				Detailed design + Process chain design (continued)
Week #2					
Monday	Project work				Project work
Tuesday					
Wednesday					
Thursday					Prototyping of test design
Friday					Project work
Week #3					
Monday	Project work (Design refinement)				Project work (Design refinement)
Tuesday					
Wednesday					
Thursday					
Friday	presentation preparation			Examination (presentation + individual oral exam)	

Fig. 2. Example of the scheduling for the thirteen weeks periods of lectures followed by the three weeks project work..

Therefore the three weeks project is an important part of the course and is recommended to all students from the theoretical introductory course. Indeed it allows the students to apply their knowledge, skills and competencies acquired from the lectures. It also mimics an industrial project, reinforcing the link to real world. Moreover, it can be seen as a prolongation of the Delta Design game in real life and provides a ground to further reflective design

practice. This organisational part is also of interest in the evaluation of the project and the assessment of the students.

The 3 weeks course starts with a kick-off meeting where an on-purpose very rough list of requirements is given to the students and where they learn about their assessment. Each student is assigned to a speciality regarding his background, level, etc. In addition to the four roles of tooling, joining, polymer processing and metrology, the one of project manager, in charge of organising meetings and keeping track of time, availability, delay and enhancing the communication in the group is created. Sometimes the teachers impose the population of that role and sometimes some students fill it up themselves. The students have to produce a report in common with specific parts related to their field of speciality. They present their project at the end of the three weeks in front of a jury composed of teachers and external sensors and are furthermore questioned individually on their speciality and general concepts on micro technologies.

An application often chosen as topic for the project is a micro fluidic device. It is so because of the relatively intuitive understanding of the general concept. An example of such specifications could be a fluid mixer. E.g. two chemicals have to be inserted with syringes and shall mix in channels. They end in a chamber where the mix can be assessed through a change in colour. The project includes functional design, material choice and process planning, testing, etc. At the beginning of the project the students have a very contextualized and fragmented knowledge about micro technologies but in most of the cases they succeeded in designing a complex process chain and obtained a functional device, somehow meeting the starting requirements. They not only succeeded in each step of the design and manufacture but also in their aggregation.

A special version of the course included a project with the aim of producing the “world smallest USB-powered espresso coffee machine”. This project obviously fit into the category of “fun project” and it encountered great success amongst the students. The final device featured a water container, a coffee powder container, a heating unit, a filter and a collection unit for the brewed coffee. The overall size approximately 30 x 30 mm and the channel and filter system has a variety of dimensions going down to 100 microns. The chosen technical solution was realised in polymer material and the working principle is directly inspired by the “Italian mocha.” It can lead to very complex calculations as it is highly multi-physics. Heating the water was achieved using a built-in electrical resistance introduced during the embossing process. The chosen process chain included micro milling, hot embossing, assembly and laser welding. Figure 3 illustrates the proposed design (left) as well as an illustration of the final component for testing (right).



Fig.3. Micro coffee machine: conceptual design and final product held between two fingers.

THE EVALUATION ISSUE

The evaluation of the theoretical course is based partly on reports (by groups of two or three students) and on a final two hours written examination. The reports' aim is twofold it links products and processing in a real case example and it also prepares the students for the exam. Indeed each group is given a micro product (a description in an article, sometimes an actual part). The first report is based on functionalities with a link to critical micro features and targets a possible re-design of the part. The second report builds on the first one and focuses on the process chain to manufacture the given micro product in the case of the chosen re-design. As the second report is situated after the middle of the course the student should have the necessary knowledge to chose and describe the new process chain. Indeed, the final written exam consists of two technical drawings of micro parts that need to be studied in order to highlight critical micro features and to produce relevant descriptions of process chains for prototyping and full production. All aids are allowed as it is a matter of aggregating knowledge related to manufacturing, functional issues and the analysis of downscaling. The authors believe that completing the reports gives a good chance for the students to practice for the exam. Of course activities during the course are aimed at gradually getting the students to a level of proficiency allowing them to achieve all necessary actions in order to perform well at the exam.

In addition to technical skills, the authors believe that evaluation should be based also on communication skills. Indeed engineers use a significant portion of their time writing reports, crafting oral presentations... Moreover in the multidisciplinary framework for product development, negotiation and communication are everyday activities performed by designers. A pertinent evaluation should reflect it. Therefore the evaluation of the practical course involves a group presentation based on a sideshow presentation and a common report. The report also must contain description of and reflections on the project management during the 3 weeks. This allows to judge the technical knowledge acquired during the course as well as organisational skills and communication skills. In order to get an assessment of each student an individual oral examination is carried out after the common presentation. The questions are based on the role the student played in the project, global knowledge about the whole design process and specific micro technology knowledge.

ADAPTATION OF THE COURSE SET INTO A TWO WEEKS PHD SUMMER SCHOOL

The time frame of the summer school is very limited compared to the graduate “mother” courses, and the wide range of participants makes it even more multidisciplinary. It is composed of two weeks with approximately 8-10 hours of work per day. Nonetheless it was decided to keep the same structure and more importantly to keep the project work with actual hands-on experience and devices production. Two lecture slots are planned each morning and attendees were asked to actively participate in most of them. Whenever necessary, exercises and practical works are held as in the graduate course but of course fitting the time constraints. Lectures are placed usually during the morning and practical work is done during afternoons. The lectures in the morning would cover the necessary knowledge needed to continue the product development of the afternoon project, together with some technical workshops for more specific and applied knowledge and practice related to equipment in a “just in time” approach.

Concurrently, the attendees are asked to complete a design project running during the whole course length. For this work, the students are split into groups. In order to have successful working groups, the Delta Design game (as in the “mother” course set) is used again, which then not only teaches the collaborative nature of design activities but also helps the students to know each others better as they will be put into teams according to the same structure. The grouping is made in an arbitrary manner by knowing in advance the PhD study topic of the participants. The project starts the second day by some functional and process chain

design (based on a list of requirements from the teachers, it can also be done in accordance with industrial needs) then moves to tooling, production of prototypes (in a "mass" production scheme) and testing of physical implementations of the design during the whole length of the two weeks. The last day a presentation of the project stands as a wrap up of the course and evaluation.

As this summer school is held in collaboration and with the sponsorship of various institutions (for instance the 4M - Multi Material Micro Manufacture former European Network of Excellence, now association (<http://www.4m-association.org/>), the French Embassy in Copenhagen) several international researchers and teachers are asked to give guest lectures; and one guest lecturer also acts as an external censor during the last day presentation. Furthermore, each group completes a report as documentation for their work. In order to reach a significant amount of working hours for 5 ECTS points the students also have to produce a conference proceeding-like paper and a short introduction to their PhD subject (held around the middle of the course). The papers are then grouped into an addendum to the lecture folder provided.

DISCUSSIONS AND CONCLUSIONS

A graduate and PhD level course in the field of micro / nano mechanical products has been presented. The course is closely linked to industrial reality and to the key technologies within the field. Moreover, a specific innovative way of teaching it through products, methods and manufacturing techniques (PMP) is developed, applied also in research activities.

The course has been developed over 4 consecutive years, and the feed back from the students has been extremely useful and very positive. In particular the combination of theory and practical hands-on experience seems to be popular. This is one of the strongest characteristics of the course, and also the most critical point with respect to planning and execution of the course. The course requires access to laboratory facilities and also assistance from technicians. From this point of view the course is relatively expensive and labour intensive. When the course is being taught to PhD students, the ambition can be increased. In particular, the specific background of each student can be integrated into the planning of the project work. The course has been adapted and successfully run 3 times as a PhD summer school.

The overall experience of the authors is that teaching a multidisciplinary topic (as the one described in this paper) is highly supported by choosing a CDIO approach. However, a careful planning of the course is required if a positive outcome (as seen from the student's perspective, e.g. a working prototype) during the limited time should be achieved. It is also the experience that a very pro-active engagement of the teachers during the project work is necessary to guide and coach the students without falling into the "pit" of giving solutions.

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COMMUNICATION IN ENGINEERING EDUCATION – A NEW WAY OF LOOKING AT INTEGRATED LEARNING ACTIVITIES AND FORMS OF COMMUNICATION

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ABSTRACT

A new analysis and development model has been designed to make the discussion about *'integrated communication in engineering education'* more multifaceted. The model includes the two main principles of communication in education – *communicate to learn* and *learning to communicate*, and new dimensions of how learning in communication is integrated in subject courses. Active and passive integration are two opposite ways of handling integration of communication skills training in subject courses. By including this approach in the discussion about integrated learning activates and combining them with the two main principles, a model of communication aspects in education can be drawn out. The objective of the model is to more clearly and more multifacetedly point out different types of situations and learning activities where the students are given the opportunity to, in one way or another, develop their skills and abilities in work life communication. The model has been the subject of a pilot study at the Royal Institute of Technology in Sweden. In the study teachers from the bachelor level were interviewed about their thoughts on integration of communication in engineering education. In the analysis the model was a base in identifying in what sense communication was integrated and in what area the integration was weak. The results of the evaluation of integrated communication in subject courses will also be discussed in the light of the teachers' willingness to make changes in their courses. The conclusion from this study is that the teachers need to rethink in what way they are integrating communication in subject courses. On course level the model of integrated communication can be used to inspire to a broader use of different types of teaching and learning activities do develop communication skills without making a major change in the way the course is carried out.

KEYWORDS

Integrated communication, passive integration, active integration, engineering education, learning activities, informal communication, formal communication

THE NEED OF A BROADER PERSPECTIVE

Talking about integration of communication in subject courses means in a broader perspective that teaching and learning in communication takes place together with teaching and learning of technical knowledge embedded in the same courses and in the same learning activities. That results in the fact that teachers in subject courses also have to take responsibility for the students' opportunities to develop communication skills. One aspect of what is needed to be discussed is if teachers in subject courses have the knowledge on how

to train their students in written and oral communication. A common attitude from teachers that has been discussed in literature is negativity against this integrated approach because the teachers are afraid of losing time for subject content [1]. These kind of arguments can easily be overcome with the insight that *what we teach our students is not the most important thing, the main focus should not be on what is taught but on what the students are able to remember from the class and what they have learned* [2]. To be an engineer, subject and technical knowledge is not enough. It is important for an engineer to possess skills and abilities that are more than calculation and modeling, exactly that is the meaning with the CDIO concept. In a learning perspective this interaction between the subject and skills does not make the education bad or less rich of technical substance, in fact new knowledge taught in a meaningful context is more memorable over time than if it had not had that context [3].

In a study from 2010 it came clear that integration of skills and abilities in subject courses exists on paper (e.g. syllabus document, course plans) but not in reality [4]. In fact, in the learning activities and in the assignments subject contents and skills were separated and not handled equally. It was pointed out that there exists an attitude of giving technical knowledge higher priority than skills and abilities [4 s. 6]. The result of this procedure does not help the students to be good engineers with the capability to behave as engineers. In another study this weakness in newly graduated engineers skills and ability to act as real engineers has been demonstrated [5]. The result from the 2010 study indicates that the teachers need to rethink their attitude to integrated skills and it has to be better defined what we mean by 'integrated communication' in subject courses [4]. We need to rethink how we integrate communication in engineering education to better provide opportunities for our students to develop engineering skills.

As for all types of engineering skills, communication is dependent of the content and the context and communication occurs in an interaction between people [6]. Communication for an engineer include the ability to talk to people in different contexts, both in front of people and smaller groups, to be able to write different types of document to different types of receivers and to be able to communicate in different languages [7], [8]. It is common when talking about communication in education to divide the area into two main elements, 'communication to learn' and 'learning to communicate' which represents ways to handle communication integrated in education. The 'Learning to communicate' approach emphasizes that communication is dependent on the discipline and is needed to be taught that way [9]. 'Communicate to learn' is more of a pedagogical approach where the communication represents a part of the learning activity that helps the students to work with new knowledge and put it into a context i.e. make new content their own knowledge. These two approaches concern in which relation to the subject that communication should be taught. They do not explain how communication could be a part of subject courses and how it could be integrated with the learning of subject content. Integration can be done in many ways. The question to ask is if the students learn different things depending what approach the instructor choose to have. To discuss this problem we have to be able to handle different types of integrated communication in a systematic way. To support that discussion a new definition or parameters have to be introduced to describe in what way communication and subject content are integrated with each other.

Passive and active integration

Communication skills are subject and discipline dependent, which means (in an engineering context) that to learn to be an engineer the student has to learn to communicate as an engineer in an engineering context. In other words students have to learn to act and communicate as engineers, not only learn to communicate in general. Today communication is often a part of subject courses. A study from 2010 showed that it was common with communication parts in engineering courses at KTH [4] but it was less common with integrated communication. The study described a reality of courses combining subject content with training in communication, but where both course learning outcomes and assessment separated the two parts from each other. When integration of skills and abilities

are discussed, the outcomes from the study in 2010 are important to have in mind. It has to be clear if we focus on 'real integration' where training in communication is impossible to separate from the learning of subject skills, or if the communication part of the course is easy to separate. To be able to handle these two different approaches a new concept is introduced, 'passive integration' and 'active integration', defined in figure 1.

<p>Passive integration: Communication is included in subject courses but is assessed separately from subject knowledge and not included in the curricula.</p> <p>Active integration: Communication skills are integrated with subject skills in the course curricula. Communication skills are practiced, taught and assessed together</p>
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Figure 1 - Passive and active integration

Integration of communication in subject courses is something complex and not simple and can be handled in different ways. Different perspectives should not be thought of as opposites of each other and none of the different perspectives are in by itself better than another. A combination of 'passive and active integration' and the common 'learning to communicate/communicate to learn' is needed to be able to enclose all approaches described in the national higher education ordinance and the CDIO syllabus.

MODEL OF COMMUNICATION ASPECTS IN EDUCATION

When handling the complexness of integrating communication in engineering courses a combination of different perspectives and approaches are needed to give the student the ability to fully develop higher skills in engineering communication. In a broader perspective the ability to communicate as an engineer is not only to be good at formal writing and oral presentation, but also to be able to act and talk like an engineer in engineering contexts. As a part of the literature study in my master degree project a *model of communication aspects in engineering education* was developed to more easily handle the complex world of integrated communication in engineering courses. The model combines the two main principles 'learning to communicate' and 'communicate to learn' with passive and active integration. In the model the four blocks represents different forms of communication e.g. direct and indirect communication, formal and informal communication in engineering education. The model is shown in figure 2.

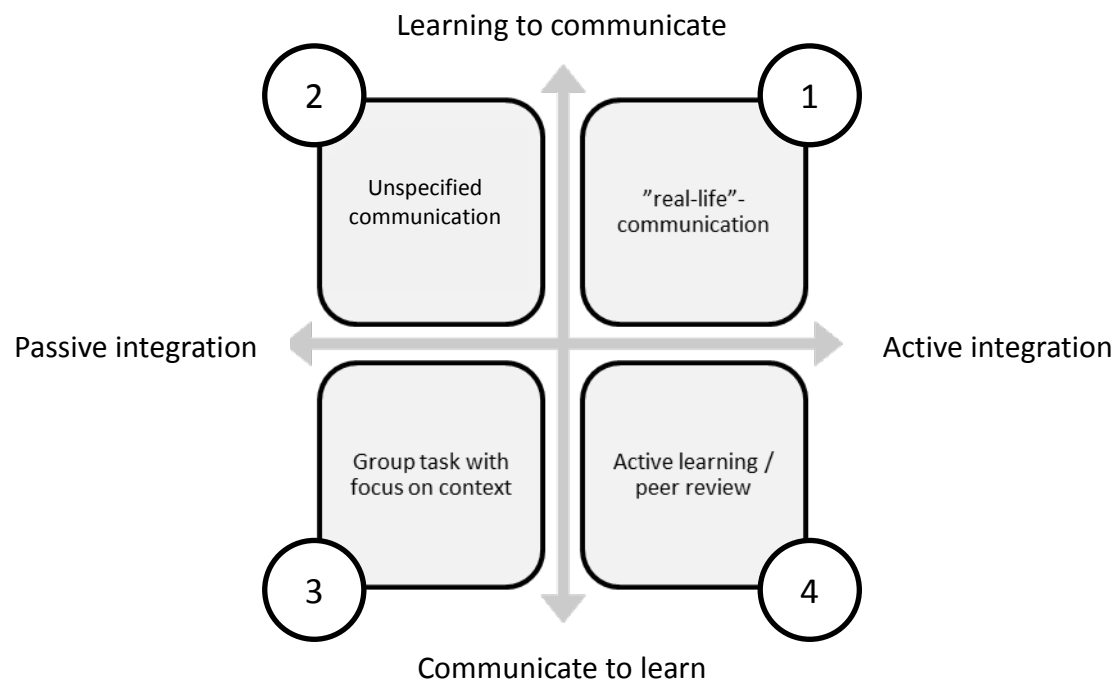


Figure 2– The model of communication aspects in engineering education

The model clarifies that communication in engineering education is multifaceted and consists of many different learning activities and different assignments and assessment tasks. To educate engineers that fulfill the CDIO-syllabus and the national ordinance of higher education in accordance with both communication skills and other skills and abilities, students need to be able to manage different types of communication skills. In the model these different part of communication are represent by the four different blocks.

In the model the vertical axis polarizes the two main approaches of using communication in subject courses – ‘learning to communicate’ and ‘communicate to learn’. These two concepts are derived from the two more known concepts ‘writing to learn’ and ‘learning to write’ [10][11]. These two describe possible aims of the communication part in the course. We have to choose if the aim is to use communication as a learning tool and as a carrier of knowledge by ‘communication to learn’, or if the aim is to provide the students with abilities in communication on a high level (as engineers) by ‘learning to communicate’. On the horizontal axis the two new perspectives are polarized. Passive integration of communication means that communication is a part of the course indirectly and the focus is not specifically on the communication parts but more communication is important to be able to handle the task/course. In the opposite direction the active integration takes place. By integrating communication in an active approach the teaching and learning is integrated in a thoughtful way where the whole learning activities integrate communication with learning in subject. This approach demands teachers to already think of integration in the planning of activates.

The four blocks and syllabus

The four blocks describes different perspectives in how communication can be an integrated part of the course. The given examples in the blocks in figure 2 are created to illustrate the core meaning of the approaches, but does not include the only potential activity or assignment. By continuously during the whole education integrating communication as described by the approaches in all blocks the student will have a fair chance to develop their engineering communication skills. In that sense none of the blocks alone is enough. An engineer is supposed to handle different forms of communication, and therefore the students are in need to practice the different forms. By analysing the form of integrated communication in the light of the Swedish national syllabus and the CDIO syllabus it is easy to see that all four approaches are important.

Block 1 Learning to communicate with an active integration approach

By integrating communication in an active way the teacher need to already 'think' integration in the planning phase of the course or lecture. This approach means that the students develop their skills when using subject content in an environment or situation that is natural for an engineer in his or her occupation. This 'real-life' communication approach is multifaceted and contains for example the ability to write a technical report in a specific format, to write a conference abstract or to be able to sell the result to a board of directors. When assessing the students both the subject part and format of the product are important because the format and the content are so integrated in each other it is impossible (or difficult) to separate them when assessment is done.

Block 2 Learning to communicate with a passive integration approach

In opposite to the 'learning to communicate with an active integration'-approach, the passive counterpart of learning to communicate do not in the specified way describe the circumstances around a specific assignment. An assignment that illustrates this approach may be a written technical report without any further instruction about format or receivers. Common with the active approach, the assessment is important but in this case it is more easy to separate the two parts from each other when the content not in a direct way are depends on the format of communication.

Block 3 Communicate to learn with a passive integration approach

The simplest way of integrating communication in subject courses may be the 'communicate to learn' with a passive approach. The idea is that the students are learning to communicate by working with subject content. This is an indirect approach seen from the teachers' perspective. That means that the teachers do not 'do' anything to support the students in the communication situation. The students develop their communications skills by their own communication to learn more and/or better. A teacher can support this process by giving students pure subject assignment to do in pair or by giving the student the optional possibility to inspect other students work. The nature of this approach makes it very hard to assess the communication skills and performance.

Block 4 Communicate to learn with an active integration approach

By using exercises with a communication focus as learning activities students can be given the opportunity to develop their informal communication skills at the same time as they consolidate and work with subject content. The active approach of integrated 'communication to learn' can take place in both large and small scale. The objective is to help the student to use all forms of

communication in an active way in the learning process. For example, if the students give each other feedback on some kind of task in an oral or written way, they do not only practice the communications skill that forms the feedback, they also need to use the knowledge of how to read and how to listen.

The number of types of activities that fits in the four blocks is huge. The scope of this paper do not include a full description of learning activities that satisfy the approaches of each of the four blocks. The model does not have the purpose to give the answer on how to integrate every approach but to give a broader perspective on in what way communication can be a part of subject knowledge. The model also does not include the versatility of communication in the sense that the skill includes ability to both in oral and in text be a receiver and a transmitter. To communicate is an ability to speak, listen, write, and read and to combine these four aspects in different ways. It is important to remember to include all aspects when designing learning outcomes in communication skills. As mentioned, the model in itself does not handle the four aspects, but for every approach each of the communication aspects can and should be included.

INTEGRATION OF COMMUNICATION IN REALITY ACCORDING TO THE OBJECTIVES IN THE MODEL

At the Royal Institute of Technology (KTH) the model has been used in a pilot study as a part of a master degree project to explore which of the four categories of communication in the model that is most common and how teachers are thinking about the concept of 'integrated communication' [12]. Teachers in different subjects and in different engineering programs were interviewed about their thoughts about communication as a part of education. The study depended on interviews with nine teachers from different parts at KTH with that in common that they all taught students in compulsory courses at the bachelor level (first cycle). The participants in the study were asked questions about their way of teaching, the presence of communication in their courses and what kind of support they needed to increase the prevalence of integrated communication in their courses. The main intended outcome of the study was to answer the two questions A and B in figure 3. The informants were asked open questions on a more detailed level. The informants were asked questions about their courses, how they were thinking when planning a lecture or a whole course and they were also asked to define what meaning communication had for them. The analysis and the aggregation of all the informants' different answers were used to answer the two main questions.

- | | |
|-------------------|--|
| Question A | To what extent do teachers use integrated communication in their courses as a part of the learning activities and in assessment? |
| Question B | In what way do teachers need support to integrate communication in their courses, both in learning activities and in assessment? |

Figure 3 –main intended inquiries of the study

As a help in the analysis of the result the model of integrated communication was used to identify types of teaching and learning in communication. The analysis was made by interpreting the transcriptions from the interviews. To the greatest extent possible the informants' answers about how they think and act around integrated communication was matched with the blocks in the model of communication aspects in engineering education.

The existence of integrated communication (answer to question A)

Regarding communication, the teachers described a reality where the students, in their subject courses, had the possibility to develop their communication skills [12]. It came clear that the teachers had a limited view of communication skills and the opportunities to in their courses help students improve their skills. In a larger perspective the teachers had a limited thinking about communication in education: communication was commonly defined as presentation skills. By looking at the informants' answers in the study, block 2 in the model (learning to communicate with a passive integration approach) was the most common type of integrating communication in engineering education. The choice of assignments and the way the informants talked about how they wanted their students to study also indicated that the students had a large opportunity to, during the study time, learn subject by communicating in a passive approach (block 3 in the model). A large amount of courses had indeed assignments that invited the students to collaborate, but the informant did not define this as practicing communication. In the interview study it also came clear that teachers have a different attitude to "pure engineering skills" than to personal and professional skills and attributes [12]. The study testifies that teachers often have a view on subject knowledge as something more important than skills and abilities. One teacher describes *'For every lab they write a report, I ask them not to write so much, just focus on calculation and so on. Because that is what is important'* [12]. Almost every one of the informants had a good understanding of how questions during lectures could provide a better learning environment. This active learning approach that the teachers were talking about fits very well into block 4 of the model.

Way of making change (answer to question B)

The study conveys a positive attitude towards developing the courses to a more integrated approach. One specific force for making changes was identified by the informants in the study – the students' satisfaction. The informants described that the most important reason to make changes in the course was the students' feedback in the course evaluations and the feeling of student satisfaction. One informant described it like *'One clue that indicates that changes should be done is if the students are not interested in what I do on lectures and if a whole class on exam fail at the same task'* [12].

CONCLUSIONS

The study from 2010 shows that many attempts to give the students the opportunity to develop their communication ability were done, but maybe it could be done in a better way according to e.g. assignments. The interview study tells us that the teachers have some knowledge of how to introduce communication in lectures. The informants had not reflected on communication in a broader perspective in that sense that is drawn out in the model. In fact, many of the informants had not reflected on communication skills as something essential in engineering education at all. The same problem has been identified in another study in 2010 [4]. The teachers are willing and able to support their students to develop subject skills and knowledge. To help students to develop communication skills the teachers are more restrictive. It is not surprising; the teachers are experts on their subject, not teaching students to communicate. But like the focus in the CDIO Initiative, it is important to integrate opportunities for the student to develop personal and professional skills and attributes integrated with development of subject knowledge. On the other hand the interview study describes a reality where the teachers were well informed in what a good teaching and learning environments depend on, but it was difficult for them to make changes due to a lack of tools. According to that, to reorganize some assignments and by in a more systematic way including communication in already existing tasks it may be possible to in an 'easy' way give the students better opportunities to develop their communication skills.

It is important that teachers start to reflect on the different types of communication skills, the use of them and usefulness. By identifying the answers to the main question it is possible to see in what area work is needed to be done to provide a better understanding and usability of communication in an engineering context.

The *model of communication aspects in education* can be used to clarify what integrated communication in education means and can be a helpful tool in the process to develop and design new courses and learning activities with the target to provide the students communication skills and help them to start to communicate as engineers in real engineering contexts. A strength in the model is that the four perspectives in the model can be applied to both oral and text based communication and it includes formal as well as informal forms of communication. The model shows what is needed to be done and in what area of the integrated communication field that teaching and learning in communication is weak.

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THE CHALLENGE OF CONCEIVING: APPROACHES TO PROBLEM IDENTIFICATION AND FRAMING

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ABSTRACT

One of the big challenges in the CDIO approach to engineering education is the first part focusing on conceiving problems to be handled and eventually solved. Traditional engineering education has been dominated by its focus on technical disciplines emphasising their individual tool box of problem solving and optimization methods. Going back to the earlier days of engineering education problems were defined through the repertoire of existing technologies and solutions taken up and handled as given cases in the education. With the growing emphasis on scientific methods leading to a continued change in engineering disciplines throughout the mid 20th century the focus changed and problems were defined in more theoretical terms. Engineering education remained dominated by its introduction of a more and more dense repertoire of methods and theoretical models.

In this paper we will approach this problem from the perspective of engineering design challenges where the need for problem identification is obvious to avoid the pitfall to reproduce and piecemeal engineer already existing product or service concepts. Problem identification is not a simple desk research task as it often involves a multitude of actors having different or even not very well established ideas of what might be a good design result.

We present two mutually supportive approaches to problem identification that we have developed, applied and refined. The first is providing an approach to map the arenas of development that influence the context of materials, visions and actors providing the basis for analysing problems related to a design task. The second is providing an approach to the co-evolution of problem space and solution space into a matching pair, which constitutes a good starting point for synthesising design concepts. The two approaches have a solid grounding in existing theories of the socio-technical nature of engineering and the process of synthesising solution spaces in engineering design.

KEYWORDS

Conceiving, problem identification, development arena, conceptualisation.

INTRODUCTION

One of the big challenges in the CDIO approach to engineering education is how problems are conceived. Though 'conceiving' seemingly constitutes the first of four components in the CDIO concept: Conceive, Design, Implement and Operate, this element is not given much attention in

the standards and syllabus of CDIO in practice. It is as if this element at the end is not too much of a concern for engineering training which is contradictory to the literature on the anticipated character of engineering problems often identified as open and wicked. Also in the CDIO concept problem identification seem to be given a backstage position compared to the methods and theories used to handle and solve problems in the view of engineering disciplines. Traditional engineering education has been dominated by its focus on technical disciplines emphasising their individual tool box of problem solving and optimization methods. Going back to the earlier days of engineering education problems were defined through the repertoire of existing technologies and solutions taken up and handled as given cases in the education. With the growing emphasis on scientific methods leading to a continued change in engineering disciplines throughout the mid 20th century the focus changed and problems were defined in more theoretical terms. Engineering education remained dominated by its introduction of a more and more dense repertoire of methods and theoretical models.

In this paper we will approach this problem from the perspective of engineering design challenges where the need for problem identification is obvious to avoid the pitfall to reproduce and piecemeal engineer already existing product or service concepts. In many engineering design courses the specifications of a new product already seem to imply a certain concept and solution space, though often these specifications may be contradictory and open for returning to the more basic question of what are the problems in the minds of involved actors that an intended design should solve?

Problem identification is not in all situations implicitly given by the practice domains of engineering though they provide a framework in which known concepts and solutions can be reproduced thereby simplifying engineering practices. It is also not a simple desk research task as it often involves a multitude of actors having different and sometimes not very well established ideas of what might be a good design result. With the complexity of engineering problems also within a given domain may ask for re-considerations of what problems are involved and thereby opening for a much wider solution space even inside a company with well established product portfolios.

Without claiming that we have the solution to all facets of the problem conception phase of engineering design we present in this article two approaches to problem identification we have developed, applied and refined. The first is providing an approach to map the arenas of development that influence the context of materials, visions and actors providing the basis for analysing problems related to a design task. The second is providing an approach to the co-evolution of problem space and solution space into a matching pair, which constitutes a good starting point for synthesising design concepts. The two approaches have a solid grounding in existing theories of the socio-technical nature of engineering and the process of synthesising solution spaces in engineering design.

CONCEIVING AS PROBLEM IDENTIFICATION

This problem of how problem identification and conceiving problems in the terminology of CDIO has been downplayed in engineering education has been taken up by e.g. Downey [1] emphasising the need for engineering training to focus much more on problem identification to sustain engineering as an innovative and creative profession. While this might be considered obvious from the point of view in attempts to characterize engineering problems as open ended and 'wicked', only few analytical texts deal with this phase of engineering activities. The activities involved in problem identification seem to be black-boxed in either established technical

concepts or solutions implicitly reflecting the problems solved or to be left to creativity and ideation often seen as outside the realm of engineering science. Even in the very comprehensive book of Vincenti [2] which puts emphasis on the role of designs and problem analysis there is a tendency to take both the character of engineering problems and the division of labour among engineers as a given. Vincenti presents a typology of phases or elements that engineering practice comprise of where design concepts are provided from the field of practice.

That engineering design concepts can be taken for granted as a pre-given repertoire may be the case for very established fields of technology and operational in large engineering corporation working in well established product areas, but even here the challenges of 'wicked' problems shows, demonstrating that even seemingly well known problems can turn out to be challenging and need careful analysis and deconstruction not taking the problem for granted and just applying known methods and designs. This comes from a basic experience that many engineering problems have elements that challenge existing designs and operate at the limits of existing and well established knowledge [3].

In a longer historic perspective some basic engineering solutions may have occupied a large part of what constituted engineering work, but the movement toward a science base was concurrent with a massive post-war expansion of government-funded research in the United States expected to result in many new technological solutions. Sponsorship of fundamental studies in a variety of areas supported the trend away from practice-oriented research and education. Successes in fields such as high-speed aerodynamics, semiconductor electronics, and computing confirmed that physics and mathematics, conducted in a laboratory-based environment, could open new technological frontiers. Military research during these years also tended to focus on performance – increased power, higher altitudes, more speed – goals that were conducive to scientific approaches. They at the same time emphasized improvement in existing design concepts, but they also asked for new ideas and solutions resulting from a multitude of new problems and challenges to engineering.

Electrical engineering, for example, no longer focused on electric power and rotating machinery, but instead, on electronics, communications theory, and computing machines. As historian Bruce Seely [4] wrote:

Theoretical studies counted for much more than practice-oriented testing projects; published papers and grants replaced patents and industrial experience as measures of good faculty. By the mid-1960s, the transition to an analytical and more scientific style was largely completed at most American engineering colleges.

Yet today, many engineering departments still have their core activities defined by technical disciplines, such as mechanics, energy systems, electronics, chemistry, building construction, or sanitary and civil engineering. Many of these disciplines have specific problems and industries that relate to their founding years, but as the demand for science-based research and teaching became prominent, the original roots to practice and industry lost their significance. With the changing demands, more abstract courses, and courses defined by scientific fields, were developed. This process may have been supportive of focusing on theories and science as the new omnipotent problem solving toolkit supporting the view that engineering problems were identified within the realm of scientific activities. A position obviously contested by new problems arising from the complexity of technological systems, environmental impacts and social reactions to technology.

The post-war decades saw the rise of systems engineering and thinking as broadly applicable engineering tools [5]. Systems sciences that include control theory, systems theory, systems engineering, operations research, systems dynamics, cybernetics and others led engineers to concentrate on building analytical models of small-scale and large-scale systems, often making use of the new tools provided by digital computers and simulations [6,7]. Techniques range from practical managerial tools, such as systems engineering, to technical formalisms, such as control theory, to more mathematical formulations, such as operations research. A broad-based movement within engineering found that these tools might finally provide the theoretical basis for all engineering that goes beyond the basic principles provided by the natural sciences. Whereas systems engineering of the 1950s could be narrowly analytical and hierarchically organized, new ideas of systems in the 1980s and 1990s focused on the relationship between technology and its social and industrial context. This new relationship and understanding of the natural and technical sciences is reflected in the notion that engineering as techno-science developed in the field of sociological studies of science and technology to reflect the new intimate relationship between these fields of science [8].

From within the technical universities, voices were raised against the consequences of a too-narrow focus on science-based teaching that lacked interest in the practical aspects of engineering work and competence [9]. Educational programs focusing on project work and problem-based learning, introduced in some experimental engineering education programs during the 1970s, spread broadly during the 1990s. They attempted to address the problems from a pedagogical and didactic point of view. In both Denmark and Germany, a few radical reform universities made project-oriented study the trademark of their education, stating that the projects could both cater to the interdisciplinary aspects of engineering methods and problem solving, and to the integration of the practical and theoretical elements needed in engineering [10].

One response to the complexity of engineering practice has been reflected in the general pedagogical reform based on project-oriented work. Project activities are also argued to provide students with a broad understanding of engineering work and problem solving, with less emphasis on theoretical knowledge represented in the courses and disciplines which is also found in e.g. the CDIO initiative [11]. In a less radical manner many engineering schools have tried to add certain new personal skills to their requirements and curriculum by complementing the natural and technical science teaching with training in communication skills, group work, and project management. These are competences that are implied in the project-oriented model and in the less demanding problem-based learning model.

The description of an engineer's contemporary competencies might include the following: 'scientific base of engineering knowledge', 'problem-solving capabilities', and the 'adapt knowledge to new types of problems'. The focus is more often on problem solving, and less on problem identification and definition [1]. This is ideally taken up in the CDIO standard as conceiving, but not explicated were much in the latter detailed curriculum plans presented [11]. This focus emphasizes the problem of engineering identity in distinguishing between engineers as creators and designers versus analysts and scientists raising question about the foundation of synthesis knowledge and design skills. The underlying assumption in most training given by engineering schools on engineering problem solving is that engineers are working with well-defined technical problems and methods from an existing number of engineering disciplines. This assumption does not answer the question as to whether engineers are competent in handling the social implication of complex technologies, and the even non-standardized social and technical processes where the problems are undefined and involve new ways of combining knowledge.

In this relation the limitations to engineering sciences and their models become a crucial part as does the understanding of technologies as hybrid constructs building on several both disciplinary and practice based knowledge components and embedding assumptions of use and social relations related to specific localities and historical settings even though these may become part of standardized socio-technical ensemble [12]. The other crucial aspect for engineering technology of the future is the handling of design challenges coming from the even more dominant role of technology in society and for the environment.

DESIGN & INNOVATION AT DTU

Since 2002, the Technical University of Denmark (DTU) has offered a new engineering education in design & innovation. This new bachelor and master program of 3 plus 2 years length represents a fundamental rethinking in engineering education. With an enrolment of 60 new students per year and twice as many qualified applicants, this new initiative is considered as a success by DTU. The new curriculum is targeted to meet the demands for competences from industry and society in the context of globalization and new cooperation structures in product development and innovation. The design & innovation education contributes to the renewal of the educational profile of DTU and is regarded as one of the recent major successful strategic developments.

Within this program several course activities focus on the process of problem identification as the important first step in working with design tasks. We will illustrate the process of problem identification from the experiences in two different courses: 'Scenarios and concepts' held in the 6th semester in parallel to the students' bachelor projects, and in 'Conceptualization' given to master students both in design engineering and in mechanical engineering. In 'Scenarios and Concepts' two approaches are core and taught in an integrated manner as the students apply the approaches on their bachelor projects. The course has been running 6 years with approximately a total of 360 students having followed it giving a rich material from the student assignments to be used as empirical material to justify and illustrate the approaches. We use this case to demonstrate that there are theoretically grounded methods and tools available that can support the students work within the process of 'problem identification' or in the terminology of CDIO in the process of 'conceiving'.

ARENAS OF DEVELOPMENT

The dominant role of technology demands multidisciplinary approaches, and challenge the science-based, rational models and problem-solving approaches. The 'arenas of development' approach is such a multidisciplinary approach having its theoretical grounding in the sociology of technology but emphasizing the role of material objects as well as social for the understanding and mapping of actors engaged in idea generation and innovation [13]. Arenas of development operate in this context of engineering problem identification as a tool to be used to map the actors and the object operating and configuring this space of change. It must cater for both the already existing solutions and configurations that sustain given concepts and solutions but also for the fluid and still open-ended and performance driven initiatives for renewal. As such it represents an initial step into the design process.

Innovation has been studied from within a number of different disciplines, and several aspects may have been caught in these approaches. Experiences demonstrate, however, that

developing new technologies involves a number of very dissimilar processes held together by various linkages and inter-dependencies. This has resulted in a definition of an arena of development being a characterized and delimited as a space holding together the settings and relations that comprise the context for product or process development that includes:

- a number of elements such as actors, artefacts, and standards that populate the arena,
- a variety of locations for action, knowledge and visions that define the changes of this space, and
- a set of translations that has shaped and played out the stabilisation and destabilisation of relations and artefacts. [13,p.190]

The definition emphasizes the different and dispersed elements of the space that comprise various localities of both a cognitive and physical nature. A 'development arena' does not generally have a specific locality or one single geographical space of existence or of central importance. However, a number of specific locations will form the stages for action in relation to each other. They do so without any pre-specified order of importance or set of relations. As a pure abstract notion 'development arena' remains metaphorical.

Companies enter arenas and specific situations when they start developing technologies and products. They may already be in an arena as a result of earlier activities. Actors might unintentionally be present in an arena. They might be represented in reduced form as competitors or users. In this paper, we limit the discussion to the analytical perspectives, although our attempt may include, as a future perspective, a discussion of managerial methods and problems.

Phenomena such as markets, customers and costs are placed into a new perspective when seen through the arenas perspective. Customers, markets etc. cannot stabilize before technologies and artifacts are stabilized as commodities. Arenas define and characterize a space and consequently also constitute the boundaries for the activities carried out on the arena. The arena is deliberately defined as an open-ended space, where certain actors and locations can be inscribed either by the actors themselves or by others engaged in the arena. The development arena should thus give us a frame for understanding and researching processes in which companies and other actors attempt to master technologies, products and markets. It includes both the static elements of locations, knowledge and artifacts, while it also frames a space for continuous action.

The 'arena' is a metaphor taken from political and social theory. It provides a tool for mapping activities that are temporary and actor-dependent within a field that structure social orderings and in which change and transitions take place. The metaphor 'arena' refers to the word's original meaning in Arabic, 'sand on sand', to indicate the special temporality and fluidity of the phenomena for which the approach provides the analytical framework. Arenas provide the place and space for socio-material interactions.

In accordance with actor-network theory, actors comprise a heterogeneous set of entities, including humans, technologies, institutions, visions and practices, which are given specific social meaning and identity through their inter-connectedness in networked relations. The structuring and stabilization within networks result from alignments and mediations that give the entities their specific meaning. These processes of alignment and mediation are core to the configuration of networks and lead to the creation of temporarily stable actor-worlds, ordering the included objects, knowledge, visions and practices [14]. Actor networks and, in their more specific and stabilized form, actor-worlds, are sense-making, semiotic networks, which in parallel

produce arenas' focus, boundaries and dynamics through their internal relations and the tensions created between the different actor-worlds and the continued processes of re-structuring and re-adjustments following them. Arenas are re-structured and eventually expand or shrink depending on the performances that actors engage in when attempting to stabilize, transform or even destroy existing actor-worlds present on the arena. The performance dimension maintains focus on actual events – whether they are discursive, organizational or material. While actors may have visions and goals that justify their actions, they often first build alliances and then, along the way, make sense of the actions and re-structuring.

Actors can even have multiple identities and engagements on an arena and being enrolled in more than one network and actor-world at the same time. Although knowledge and practices may be constrained and framed within a specific actor due to the sense-making relations that dominate within the network, other meanings might be assigned in other networks. Actors may even be engaged in several arenas at the same time and not necessarily need to coordinate and solve either conflicting views or practices.

CONCEPTUALIZATION

Text books in engineering design are in agreement about how to structure the design process. First phase comprise of an analysis that leads to a design goal after which the synthesis work starts. A concept is in this context described as an 'early suggestion for a solution' characterised by a low degree of specificity though a more precise account of what these characteristics are is not detailed. Roozenburg and Eekels [15] tend to characterise concept in terms of a solution defining the main principles of the intended design, which does not really help as this eliminates the need for a notion of concepts as they just could be characterised as principal solutions.

Dorst and Cross [16] emphasise the design process as a co-evolution of problem space and solution space as a matching pair which is in light with the understanding of these as closely related. But in the view of Hansen and Andreasen [17] this is not satisfactory either as a concept in their view must include some specific and relevant characteristics. Consequently they suggest that a concept must include some relevant and specific characteristics relating to the actual situation and stage in the design process and its context. The result is a two-dimensional definition of a concept comprising of the idea with and the idea within the concept, where the idea with must reflect the use, need and market context while the idea within reflect the specific technical aspects related to the concept realisation and the working of the design.

This definition of a concept is characterised by Hansen and Andreasen:

A conceptual design, i.e. the concept for a new product, may be seen from two sides, a need/market-oriented and a design/realisation-oriented. The need/market-oriented side explains the conceptual new way the design solves its task. The design/realisation side explains how the concept creates the necessary functionality and structural realisation for doing so.

What is seen as conceptual depends upon what is already created in the actual area concerning solving the task or concerning the principles or design of the artefact. So the conceptual new aspect could very well be e.g. man/machine interaction, form features, or choice of material. [17,p.1]

The combination of this take on conceptualisation is that it in conjunction with the arenas of development provides an approach to the demand for co-evolution as outlined by Dorst and

Cross. An approach they themselves do not provide for. The designer must in parallel identify the development arena and create new concepts to conceive and identify the problems at stake.

Within the rational problem solving paradigm and based on an empirical study Cross and Dorst develop a model of creative design as the co-evolution of problem and solution spaces towards a matching pair [16,18]. Dorst [19] explains the model as follows:

Creative design seems more to be a matter of developing and refining together both the formulation of a problem and ideas for a solution, with constant iteration of analysis, synthesis and evaluation processes between the two notional design 'spaces' – problem space and solution space. In creative design, the designer is seeking to generate a matching problem-solution pair, through a 'co-evolution' of the problem and the solution.

CASE STUDY: LIFE-SAVING IN THE PUBLIC SPACE

To illustrate the open-ended character of the process of 'conceiving' a case study is taken from the master level course 'Conceptualization' where 8 student design teams (in total 43 students were participating autumn 2010) worked on a project entitled: 'Life-saving in the public space – products, services or systems.'

We observe the project title opens the solutions space towards products, services or systems. In this sense there is no restriction of the type of solution for the student design team to conceive.

The design task was formulated as two questions for the teams to answer:

What if life-saving in the public space should be improved? Which concepts can we propose?

We observe this is a very open formulation of a design task, in the sense that neither a need nor a problem is specified. Each student design team has to identify a need and define its own design problem.

The design task formulation was supplemented with a description (to inspire the students) of some current situations in Denmark, where a possibility for improved life-saving is evident:

TrygFonden has in recent years sponsored installation of defibrillators in public places to make it possible to render an instant life-saving effort until ambulance arrives. Although the installed defibrillators are assessed by professionals to be user-friendly, early experience indicates that they are seldom used in practice. This might be fatal for a person having cardiac arrest, because the survival chance decreases for every minute the life-saving effort is postponed.

During summer 2009 10 persons died by drowning at the Danish beaches. Several holiday-makers drowned when they went for a swim. Some holiday-makers probably go bathing ignoring - or not aware of - wind and weather conditions. Others are unlucky and may be hit by a wind surfer. In any case fast life-saving effort is a precondition for survival. Ambulance men complain that the conditions for carrying through their work at road accidents are becoming more difficult. Road users passing by do not accept waiting time and delays, and nosy people crowd around the scene of the accident. Road users and

nosy people ignore requests from police and ambulance men, and therefore the injured persons and the ambulance men are subjected to danger.

What perspective develops each student design team on the design project?

First of all we observe that 5 of 8 student design teams deliberate the term 'public space':

- *When brainstorming and debating about the subject the team found it necessary to reach an understanding of what constitutes "the public space". Here the team found subject of responsibility especially interesting, for instance with concerts in public fields. In such cases there can be several different stakeholders each with their responsibility and agenda, which might not always contribute to secure activities.*
- *Every person spends some time of the day in public spaces, when going to work or to school, shopping, traveling, going for a walk or doing any other kind of activities outside home. ... But the fact is that people may encounter many dangers every day such as traffic accidents, fires, falls, extreme weather conditions and many other things, which cannot be controlled or predicted in advance. ... sometimes unplanned things can happen when a person's life is threatened and he or she cannot help themselves and become dependent on help from outside.*
- *Public space is an area or place that is open and accessible to all citizens.*
- *Among other issues concerning life-saving, a thorough and intense discussion among the team members took place of articulating what a public space stand for. ... Part of the first information search took place regarding institutional and constitutional terminologies of 'public space', according to which a public space is 'in theory what is open to everybody' as well as it can be interpreted as a social space such as a town square that is open accessible to all, regardless of gender, race, ethnicity, age or socio-economical level. Other examples of public spaces are squares, city beaches, fields, parks, quays as well as plazas, town squares, parks, marketplaces, public commons and malls, public greens, piers, special areas within convention centres or grounds, sites within public buildings or so on. ... Soon enough it became clear that public space has a multifarious meaning related to existing social activities, architectural features, community involvement, local culture and history and so on. Thus, it has to be seen in relation to life saving not as an issue to-be-deconstructed individually. Based on the primary research public spaces were categorized with regard to volumes and whereabouts. It seemed beneficial to further categorize into small and great, as well as, into created by nature itself and designed by man too.*
- *During and through the latter process some characteristics were also defined by the group for the context of the public space. These general characteristics were: Urban environment, densely populated, accident occur often, high energy traumas. High energy traumas are defined as accidents that involve the release of high kinetic energy causing massive damage to technical objects and humans.*

We observe that the student design teams have different interpretations of the term 'public space'. The first team focuses on responsibility in relation to concerts in the public field. This team found a challenge to work with life-saving in crowds being inspired by the accident at Roskilde Festival year 2000 during a Pearl Jam concert, where 9 young men were killed, and the accident at Love Parade in Duisburg, Germany year 2010 where 21 were killed and more than 500 injured. The second team sees public space as 'outside home', and an accident in public

space is a situation where a person's life is threatened and where the person is dependent on help from others. Whether these others are professionals (ambulance men, firemen or police officers) or civilians passing by is not discussed. The third team defines public space as open and accessible. The fourth group has the most elaborated discussion of the term and identifies four attributes of public spaces, viz. accessibility, volume and whereabouts, created by nature or man. The fifth group's interpretation of 'public space' is closely linked to accidents happening in cities, especially traffic accidents, where a car runs into a pedestrian or a cyclist.

The 8 student design teams formulated the following design problems:

- The first team defined their problem as life-saving in crowds. This group sees a solution space consisting of flexible barriers, which will not result in accidents (crush hazard) when a crowd goes into panic.

Four other student design teams focus on ambulance response in case of an accident:

- One team defines their task as *Alarming road users*. The team sees the answer to response of ambulance in a cleared road for the ambulance, so it is possible for the ambulance to drive fast. In order to obtain a cleared road the road users shall be warned about the fast ambulance as early as possible and the aim is to design an alarming system to alarm road users. The system should provide the road user more awareness of the ambulance coming and where it is coming from and in this way take into account the safety for the paramedics and road users.
- One team formulates a mission statement: *The Ambulance/Victim Protection must quickly ensure safe working environment for the paramedics as well as improving their working conditions without the need for involvement of other rescue units*. The team sees the answer to ambulance response in the fast establishment of a safe workspace for the ambulance men at the scene of the accident, i.e. ensuring that road users passing by the accident do not disturb or expose the ambulance men for danger.
- One team writes a short problem formulation: *When looking at cross-sections, how can the transport of an emergency vehicle be improved?* The team sees the answer to response of ambulance in cleared cross-sections, which means that ambulance drivers do not have to lower speed when approaching cross-sections.
- One team writes: *In case of a car accident, help is called for manually. The caller in question will have to state the location and then wait for help to arrive. If the person involved in the accident is not able to call for help, the person will have to rely on by-passers taking action. If there are any!! In case the driver is unconscious the driver cannot make the call. And if no one is around the driver can risk waiting for a long time. Simultaneously, when help is called, the emergency team does not always get the exact location from the caller, which will delay the arrival of the help*. This team sees the answer to ambulance response in an alarm call immediately after the accident has happened and an alarm call containing information of the exact location of the accident. The team focuses on automatic GPS systems in the car being activated when the airbags are activated.

We observe that although the four student design teams focus on the same issue, the ambulance response in case of an accident, they find four different matching pairs of problem and solution space. One team defines their problem statement as: *How can the awareness and localization of a man overboard be improved?* This team sees the problem related to rescue

missions at sea, where the helicopter crew today depends on vision to localize a person overboard. Rescue missions are often in rough weather conditions, and vision systems, e.g. infrared camera or a flashing light on a life jacket, are not optimal. The team focuses on the life jacket having a GPS device to signal position.

CONCEIVING IN THE CDIO VERSION

The CDIO concept is detailed in the following table where more details are provided concerning the content of the four acronym letters:

<i>Conceive</i>	Defining customers needs, considering technology, enterprise strategy and regulations, and developing conceptual, technical and business plans.
<i>Design</i>	Focusing on creating the design; the plans, drawings, and algorithms that describe what product, process or system to be implemented
<i>Implementation</i>	Refers to the transformation of the design into the product, including hardware manufacturing, software coding, testing and validation.
<i>Operate</i>	Uses the implemented product, process or system to deliver the intended value, including maintaining, evolving, recycling, and retiring the system

Figure 1. The Four elements of the CDIO concept [20,p.8].

The dilemma related to these elements is that they seem to neglect the socio-technical competences as well as competences to work with synthesis as also demonstrated in the following definition of the CDIO goals:

Master a deeper working knowledge of technical fundamentals defined by: Engineering education should always emphasize the technical fundamentals ...deep working knowledge and conceptual understanding is emphasized to strengthen the learning of technical fundamentals ...In a CDIO program, the goal is to engage students in constructing their own knowledge, confronting their own misconceptions". . Instead the CDIO concept with its three overall goals seems to be enrolled in a classical techno-science discourse, emphasizing the 'technical fundamentals'. [206,p.20]

While in the DTU program the phase of conceiving the problems and demands that can be identified in the use context of designs of products, services or systems has been given a very high priority in accordance with the earlier stated imbalance in engineering education between (socio-technical) problem identification and (technology-driven) problem solving not much can be found elaborating of the meaning of 'Conceiving' in CDIO. In fact this 'letter' has only been given a few lines in the complete book outlining the principles, goals and standards. In the listed priorities of the syllabus point 4.3 detailing what is meant by *conceiving* includes: 'setting systems goals and requirements; defining function, concept and architecture; modeling of systems and ensuring goals can be met; project management' [21,p.56]. At another place *conceive* is understood as 'interaction and understanding the needs of others' [20,p.28]. Nicely followed up by this general statement:

In a CDIO program, experiences in conceiving, designing, implementing and operating are woven into the curriculum, particularly in the introductory and concluding project courses.
[20,p.28]

This underpins that the focus in CDIO still is on engineering as a self-contained and complete discipline of both knowledge and skills implying that no other types of knowledge is given a similar status.

CONCLUSION

The role of engineers in technology and innovation is often taken for granted. Even in future-oriented reports on engineering, there is a tendency to expect problem-solving abilities in societal and environmental issues from engineering, without challenging contemporary foundations of engineering curricula. Innovations during the last decade are leading to changes that may make the role of engineering less central in the future. Policy and management attempts to govern innovation processes have also broadened the scope and shifted the focus from technological development and breakthroughs to a broader focus on market demands, strategic issues, and the use of technologies. At least in the context of a design engineering education much more emphasis should be put on methods to handle the conceiving phase of engineering work. This includes a need for taking up approaches inspired from the field of science and technology studies (STS) like the arenas of development approach as well as advanced approaches to conceptualisation as e.g. developed in relation to the processes involved in design ideation and synthesis.

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AN APPROACH TO FOSTER INTEGRATIVE SKILLS DURING THE ENGINEERING STUDIES

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ABSTRACT

This paper presents an approach to overcome the drawbacks associated with education programs developed on the basis of domain-specific knowledge only. The approach is based on establishment of means for cross-disciplinary meetings and collaboration between students on Master programs in product development and production management. The approach is intended to help reducing the barriers to integration among individuals possessing different competences that have been reported in the literature. The approach originates from discussions regarding two Master programs at the School of Engineering (JTH), Jönköping University, Sweden. The programs are: Master in Product Development, specialisation in Product Development and Materials Engineering and Production Systems, specialisation in Production Development and Management. Both programs are designed according to the principles of the CDIO initiative. The approach was developed jointly by the two Master program coordinators during a workshop at Stanford University on 'Changing mindsets: Improving creativity and innovation' in December 2010. The workshop was organised by the Swedish program 'Product Innovation Engineering program' (PIEp). The approach emerged during the workshop and was modelled as a physical prototype and discussed with other workshop participants. The result was three courses found to be suitable for joint studies.

KEYWORDS

Master programs, Integrative skills, Cross-program collaboration, Teaching, T-shaped people

INTRODUCTION

The need for integration between product development and production to achieve prosperous innovation has been advocated by both researchers (e.g. [1,2]) and practitioners. The underlying rationale is that integration supports individuals that represent different organisational units, and thus competencies, to collectively engage in problem solving during product development [3,4]. However, integration is not easily achieved. Research has revealed various barriers that might inhibit integration. These barriers include personality, cultural, language, organizational and physical differences [2,5].

Despite the convincing arguments in literature and the claims from industry that integration skills are vital, the education system poorly reflects the need of such skills among engineers. Engineering education programs are often constructed on the basis of domain-specific knowledge. Less efforts are devoted to allow cross-domain insights among the students. Consequently, the engineering students do not possess the necessary highly valued integrative skills that seem to be one of the factors leading to competitive advantage in industry.

As an example, engineering students on product development programs and production management programs seldom meet each other during their studies. Even more seldom, or in many cases never, they interact in courses or other program activities. In this paper an approach to overcome this insufficiency of current engineering curriculum is suggested. The idea behind the approach is to ensure that product development students and production management students meet and collaborate during their time at the university. This is believed to increase mutual understanding of each others' competences and therefore it might reduce the barriers to collaboration when they become practising engineers c.f. [2,6,7].

The paper is structured as follows. First, the structure and contents of the two master programs are briefly outlined. This is followed by a short description of the purpose and methodological considerations. Thereafter the approach is introduced, followed by a discussion about T-shaped engineers. The paper ends with some conclusions and discussion.

STRUCTURE AND CONTENTS OF CURRENT MASTER PROGRAMS

This section gives an overview of the master programs in Product Development, specialisation in Product Development and Materials Engineering and Production Systems, specialisation in Production Development and Management, respectively. Both programs are supported by a steering group with representatives from various industrial branches reporting about the industrial needs. In common for both programs is that all teaching is given in English, and the students come from many different nationalities and cultures. In order to overcome some of the potential barriers described above, students from both programs are given a short introduction in multi-cultural competence. The aim is to train the students in the basics of intercultural communication.

Product development, specialisation in Product development and materials engineering

As competition between companies gets tougher and the number of products on the market increases, many come to realise the importance of product development and materials knowledge as competitive means. The program aims to develop the knowledge and skills that are needed to develop and design advanced products with the use of modern information technology regarding knowledge-management and modeling. It also aims to develop knowledge in applied mechanics, modeling, and simulation in order to optimize product function and performance, material selection, and manufacturing processes. This includes a deeper knowledge concerning technical materials and how they are manufactured, their structural design, properties, and how they can be used in products.

The program plan and its progression is shown in Figure 1. This structure is based on the three research areas Materials and manufacturing, Computer supported engineering design, and Simulation and optimization. Courses related to each of these areas respectively are given parallel through the program, with increasing degree of difficulty.

The use of computer based methods and simulation tools are extensive in most of the courses, and the program gives an understanding of the theory behind and the practical use of these computer based tools. In most of the courses the students have the opportunity to work in projects.

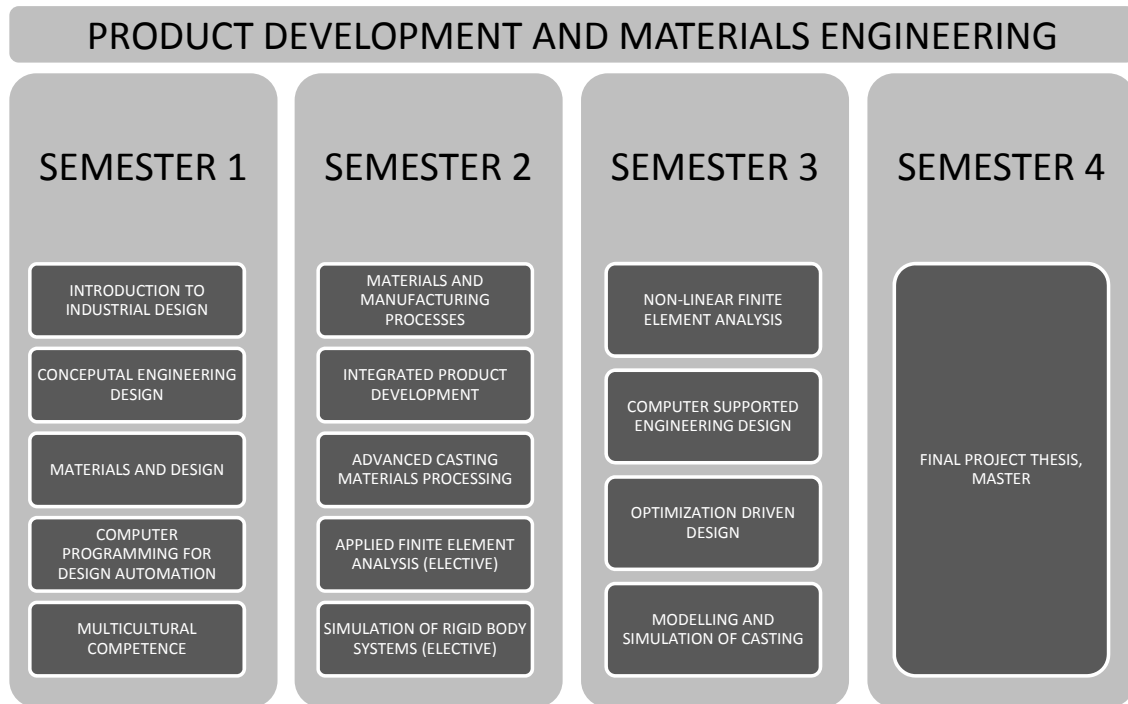


Figure 1. Current program plan for Product development and materials engineering.

Production systems, specialisation in Production development and management

The Master program in Production Systems, specialisation in Production Development and Management aims at contributing knowledge and overall understanding about industrial production systems and competitive production. The program develops the knowledge and skills that are needed to organize and manage the design, implementation, start-up, operation, further development and maintenance of industrial production systems.

The program structure is illustrated in Figure 2. The program starts with a few courses that provide the students with a common starting point for the following profile courses which address industrial production from two perspectives: development and operation of production systems. The development perspective focuses on the design and development of the production system as well as the possibilities and limitations that are related to the design of products and the supply network. The operation perspective focuses on how materials and information should be planned, monitored and transferred within as well as to and from the production system. The operation perspective also focuses on how the production is organized to achieve efficient and effective production. Moreover, the interaction between technology and humans in the system is addressed.

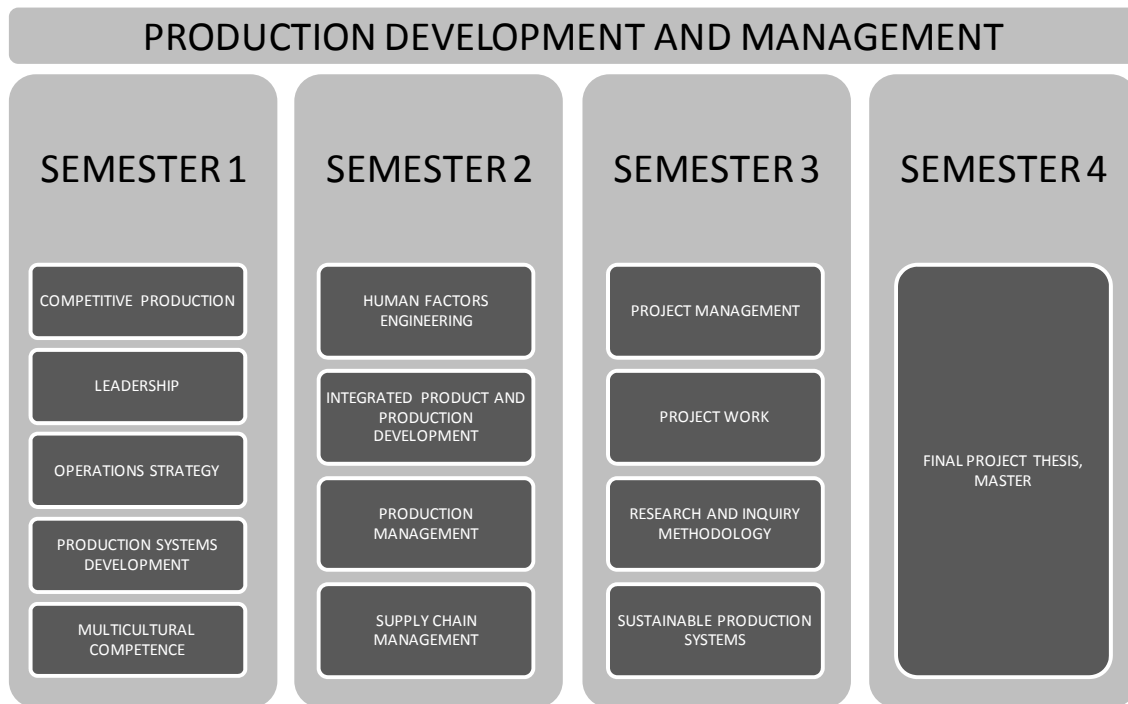


Figure 2. Current program plan for Production development and management.

PURPOSE

The purpose of this paper is to present possible cross-disciplinary activities between the Master programs in product development and production systems, in order to foster integrative skills among the engineering students during the studies. Today, there is no interaction at all between students at the programs, and identification of any possible joint courses or other activities will lead to increased co-operation. Ultimately, this will result in students that are more attractive to industry because they are better prepared to meet the industrial needs.

METODOLOGICAL CONSIDERATIONS

The approach presented in this paper was developed during a workshop on 'Changing mindsets: Improving creativity and innovation' in December 2010. The underlying idea of the workshop was the need of continuous upgrades and revisions to existing curricula's and faculties' pedagogical methods and processes. The workshop was organised by the Swedish program Product Innovation Engineering program (PIEp, that is financially supported by VINNOVA – the Swedish Governmental Agency for Innovation Systems). The workshop was hosted by Stanford University, which was chosen because it is a place where creativity and innovation is indigenous to the campus culture. As the workshop focused upon various issues related to creativity and innovativeness, the idea was to inspire changes to the engineering curricula that the participants were responsible for.

The participants at the workshop had various teaching and education responsibilities within their organisations and represented different Swedish universities, including the Royal Institute of Technology, Lund University, and Jönköping University. A majority of the participants were responsible for different bachelor/master programs or specific courses.

Two of the participants were the program coordinators of the master programmes outlined above.

During the workshop we jointly and critically reviewed the two master programs to identify potentials for increasing the integrative skills among the engineering students in both programs. Essentially, the goal was to find courses within which students from each program could be engaged in collective activities or to develop one or a few courses that would be included in both programs. As one of the issues addressed during the workshop concerned prototyping and all participants were given the task to model a change in their program or course as a physical prototype, we aimed at developing a physical prototype illustrating how the programs could be modified to enhance the student's cross-disciplinary knowledge. The approach presented next in this paper thus emerged as a result of this joint program review and physical prototyping of suggested changes.

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The result from the workshop, and the resulting prototype, is shown in Figure 3. This picture illustrates the physical prototype which was the outcome from the prototyping activity during the workshop. The prototype illustrates the key challenges and core aspects of the approach to foster integrative skills among the students of the master programs.

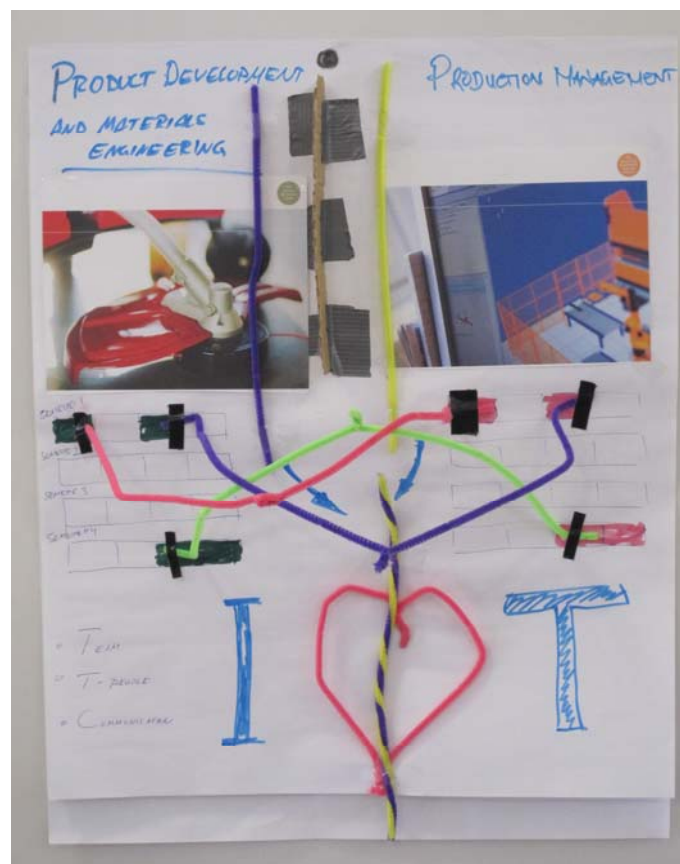


Figure 3. Prototype made during the workshop.

On top of the prototype, the programs are separated by a “wall”. This “wall” illustrates that there is no interaction at all between the programs and their students today. Students that belong to each program respectively are symbolized with different colours, purple sticks represent students from product development and yellow sticks represent students from production systems.

On the next level, the program plans are shown, and courses found suitable for joint studies are connected with wires. This level describes what can be done to increase the integrative skills, it is also illustrated without the “wall”, showing that now there is an interaction between the programs. Figure 4 is a simplification of the most important results from the workshop and prototype and shows the courses identified for joint studies.

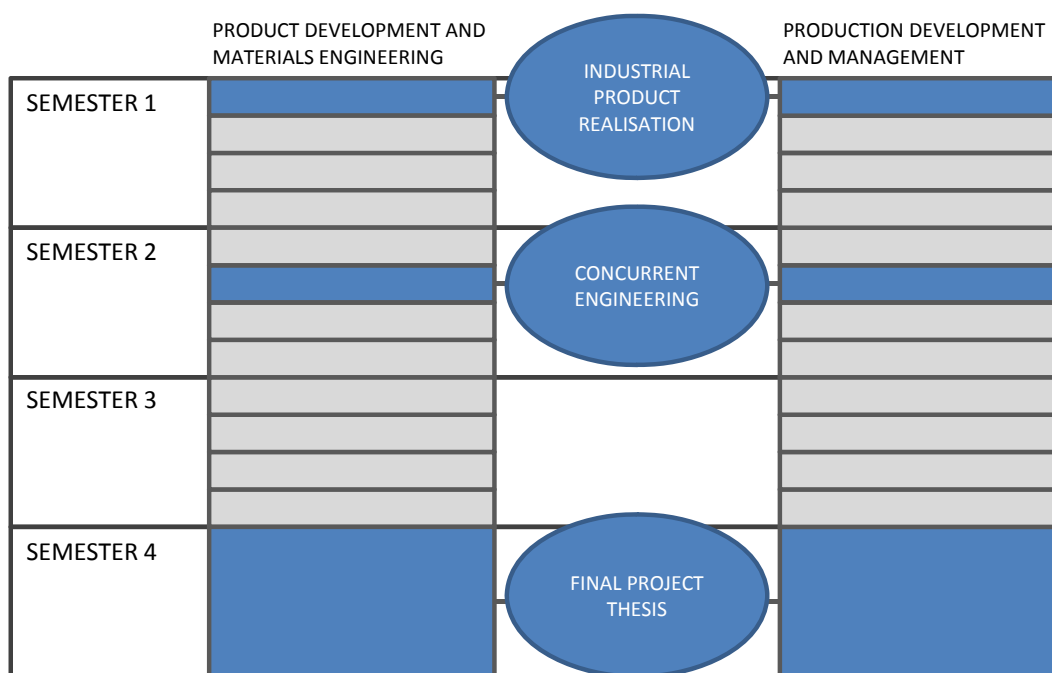


Figure 4. Three possible joint classes were found.

The first suitable cross-disciplinary activity was identified already in the first segment, the introductory courses. In both cases, the program starts with an introductory course. In the master program in Product Development, specialisation in Product Development and Materials Engineering, the first course is Introduction to industrial design. The program in Production Systems, specialisation in Production Development and Management, starts with a course in Competitive production. During the workshop it was realized that these two courses could be replaced by a common introductory course, where students from both programs jointly study the course. This new course was suggested to be entitled Industrial product realisation, and cover both product development and production-related issues from an industrial perspective. There are at least two reasons for this joint course. First, it provides an opportunity for the students to get to know each other and thus develop personal relationships supporting future collaboration, and this is encouraged already from the beginning when the programs start. Second, it gives the students a common platform of background knowledge for their continuing studies. This common platform makes it easier for collaboration in later courses, and also when the students become practising engineers. It is suggested that this introductory course contains projects where students from respective program work together.

As this is an introductory course, the projects will be of a more general kind, covering aspects related to Industrial product realisation in general. The projects will be individual putting higher demands on the supervision. However, as this course is intended to be given by several lecturers coming from different disciplines, supervision will be shared among the teachers. The number of students in each project team depends on the number of students following the course, but approximately four students, ideally two from each program. The projects will, as far as possible, be performed together with the industry and based on a relevant industrial problem.

The next opportunity found suitable for joint studies was in segment three, year one. Today, students on the master program in Product development have a course about Integrated product development. The aim of this course is *"...to give the students knowledge and an understanding of how a product's design is affected by, and has effects on, important aspects related to different interested parties and life-cycle phases. The course will present different approaches to support integrated product development. The integration of design and production is specially emphasized."* At the same time, students on the master program in Production systems study the course Integrated product and production development. This course *"...aims at providing the students with knowledge regarding how activities carried out and decisions taken during product development affects the possibilities to achieve efficient and effective production."*

As the goals and contents of the two courses to some degree overlap, it was realised that the courses could be combined into one course only, with the suggested name Concurrent engineering. The course will specifically focus on aspects related to concurrent development of products and production systems as well as the need for co-ordination and collaboration between product development engineers and production management engineers. Also in this course the engineering students from both programs work in a collaborative setting on a project task which illustrates the complexity and interdependencies that exist between product development and production. In these projects there will be an increased focus on teams and problems based on the different competencies, and also the degree of industrial participation will be higher.

In both programs, the studies end with a final thesis project. This was identified as a third possibility for joint activities. The goal is to set up thesis projects with one student from each of the programs. Each student is supposed to work with questions related to their specialisation and field of knowledge, but they should do so together in the same project. This also means that each student is examined separately, and on the same basis as if the whole thesis project was strictly limited to the individual disciplines. The supervision will also be shared between the competences. All of these projects will be based on a relevant industrial problem, and therefore in all cases involve companies. Among the advantages is the possibility to gain experience about cross-disciplinary work, but also the possibility to arrange more extensive projects, which might be more attractive for industry because the projects can address highly relevant problems that companies face.

All these three activities, or joint studies identified, have one common advantage, nothing else need to be changed in any of the two schedules. This will make it much easier to implement the changes. These activities also serve as a means of encouraging the students to work together interdisciplinary.

The bottom part of the prototype shown in Figure 3, or bottom level, mainly describes the expected outcome from the cross-disciplinary studies and joint activities. On this level, the coloured sticks, representing the students, are twisted together, symbolising the interaction and collaboration between them. These students, with cross-disciplinary skills, are now better prepared for work in teams with people from different disciplines. They will also be better in communication between the different disciplines.

Finally, as the prototype shows, the result will lead to more T-shaped people (described in the next section of this paper), symbolised by I love T.

T-SHAPED PEOPLE

T-shaped people, or people with T-shaped skills, are professionals with interdisciplinary capability e.g. [8,9]. These people will still have the same depth of knowledge as I-shaped people, but in combination with the broader communicating capability and understanding for other disciplines, they can collaborate and solve problems across the disciplines. They are actually more willing to collaborate, innovative, and more adaptable to any situation. These qualities are important in many situations, e.g. in problem solving, brain-storming, and needed to build a creative environment. They have the ability to shape their knowledge to fit the different situations. The T is described in Figure 5, where the vertical stroke illustrates the deep knowledge and the horizontal stroke describes the interdisciplinary skill.

The cross-disciplinary activities outlined in the approach presented in this paper will lead to an education where the students are fostered to become T-shaped people. The students from the programs described above will become more like T-shaped professionals, and be better prepared for the newer demands from the industry. Collaboration across the programs during the education provides a means of getting used to discuss and work across disciplines. These students are more likely to establish a good understanding for each other making it easier for them to solve problems together. However, it is important that the disciplinary depth and skill still are there, without the deep knowledge, the broader part of the T does not mean anything. It is the combination of the depth and breadth that is the success.

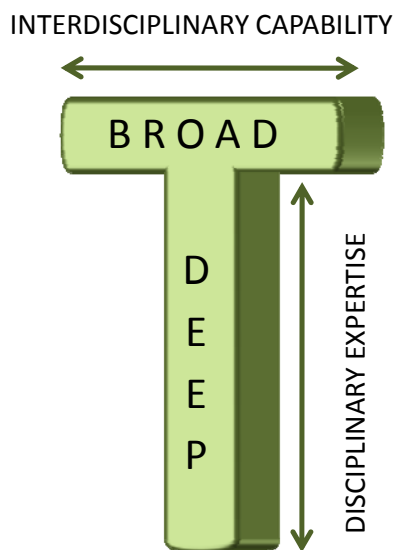


Figure 5. T-shaped people, disciplinary expertise in combination with interdisciplinary capability.

There is a need to develop a more T-shaped education. The higher education of today provides a good quality with regard to the vertical stroke in the T. However, there is deficiency when looking on the horizontal, interdisciplinary, stroke [9]. One way to bridge this gap and develop a more T-shaped education is the cross-disciplinary activities described in this paper.

CONCLUSIONS AND DISCUSSION

This paper has presented an approach to foster integrative skills among engineering students. More specifically, the approach aims at overcoming potential barriers to collaboration between product development engineers and production management engineers, c.f. [2]. The core of the approach is that the engineering students should meet and collaborate in a number of activities during their studies. Implementing such activities, in terms of joint courses, in the master programs will result in T-shaped people that are more open-minded for others' competences and better prepared to engage in collaboration. This prepares the students for the needs of industry and thus for a prosperous career as engineers.

Within the product development field prototyping is defined as “*an approximation of the product along one of more dimensions of interest*” [10]. Physical prototypes are tangible artefacts used for learning, communication, integration, or as milestones (ibid.). As was mentioned above, the workshop participants were given the assignment to model changes to their programs or courses as physical prototypes. The underlying reason was to stimulate creativity and to communicate the changes made in an unusual way. Normally, changes to curricula are presented in written texts or perhaps as illustrations. Rarely are physical prototypes used. The development of physical prototypes clearly helped to induce creativity among the participants. Our experience is that the prototyping activity assisted to generate a clear focus of the discussion on which changes should be introduced to the programs and how these changes should be communicated in an unambiguous way.

Referring to Ulrich and Eppinger's [10] argument as why prototypes are used, the prototyping activity became a learning tool for when the approach was developed. As we are responsible for one Master program each, we needed to get good insights into the other's program. This was a necessary first step to be able to discuss potential changes that could be made to the programs to increase the cross-disciplinary contents. So when we started to develop the prototype it facilitated the learning from each other about the two Master programs, respectively. The prototype also became a tool for integration, which was at the core of our ambition during the workshop. That is, we strived to find ways to increase the cross-disciplinary knowledge among our master students and by using the prototyping activity it helped us in the search for such ways. The development of physical prototypes induced a number of iterations where different solutions were modelled and compared. This leads ultimately to the approach presented in this paper. Perhaps the most valuable use of the prototype was its ability to support communication. One of the strengths of physical prototypes is that they contribute to enriched communication. Tangible and visual representations are fairly easy to understand compared to verbal descriptions or sketches. This turned out to be true when we presented our ideas for program changes to the other workshop participants.

A key criterion that contributes to the quality of a Master program is how it is embedded in or supported by a dynamic research environment. That is, a program that has close links to extant research and active researchers provides the students with up-to-date knowledge. At the JTH the overall research focus is 'Industrial product realisation, especially applications for small- and medium sized enterprises'. The research focus of JTH includes four research areas: Product development, Industrial production, Materials and manufacturing, and Information engineering. Each of the four research areas provide the students with domain-specific knowledge. However, industrial product realisation is cross-disciplinary *per se* as it involves all activities from idea to finished product. As has been argued earlier in this paper, well-functioning engineers need also to have cross-disciplinary knowledge. The inclusion of a course in each of the two Master programs on Industrial product realisation thus provides the students within both programs with such knowledge. Moreover, it may also facilitate recruitment of students who want to continue their carrier within academia.

The course gives the student a possibility to understand what Industrial product realisation is and how their domain-specific knowledge relates to other types of knowledge fields. By giving the students chances to collaborate with others that have complementary knowledge during their education open up possibilities for cross-disciplinary research. Those students that continue with postgraduate studies might then be able to pose research questions that do not only remain within their specific field of knowledge. It is believed that they will be more motivated and capable of working together with other researchers outside their own domain.

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Mutual Workshops enhancing Curriculum Integration

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ABSTRACT

The BSc Eng programme in architectural engineering at DTU Civil Engineering is organized in accordance with CDIO principles. We have been working with CDIO principles for 2-3 years now, and in the following we present the process and adjustments that were made, with the third semester as a case.

Every semester has a teaching team consisting of all the teachers for courses in that semester. Each semester also has its own theme and a multidisciplinary, joint project. So the most active members of the teaching team, of course, are those responsible for courses that address the theme and contribute to the joint project.

The theme of the third semester is 'structural design'. Structural design is defined as an integration of material science, statics and geometry in relation to an architectural project. Anticipating the implementation of CDIO and this theme, major changes were made to the curriculum. A course in material science was moved from the fourth to the first semester so that the project could be informed by material science. A new course in geometry was prepared and software that could facilitate an integrated design project was introduced (STAAD Pro).

The 'full package' of the new third-semester project in structural design was realized for the first time in autumn 2009. This paper presents the lessons learned from this first round along with the changes they inspired. Amongst the biggest changes made was the introduction of a successful joint workshop between the geometry course and the design course. This realized the full potential of structural design and firmly highlighted the creative potential in geometry for hesitant students. The joint workshop also showed potential as a general tool that can enhance curriculum integration.

KEYWORDS

Curriculum Integration, Architectural Engineering, Geometry, Structural Design, Design Projects

Introduction

Introduction

The principles of CDIO (conceive, design, implement, operate) have been a part of the DTU Architectural Engineering programme for several years. One of the main features of the programme is to give the students mandatory design-implement experience. This experience teaches students personal and interpersonal skills, and product, process and system design and implementation skills, and at the same time reinforces disciplinary knowledge [1].

In order to create a framework for this, the curriculum was organized in 4 semester themes, and each semester was facilitated by a teacher team, consisting simply of all the teachers for the courses of that particular semester.

1. Introduction to Architectural Engineering
2. Project management
3. Structural design
4. Indoor and energy design

DTU Architectural Engineering has a fixed curriculum with no elective subjects in the first 4 semesters. Ideally, this should allow for the implementation of that most ambitious of curriculum organization models: an integrated curriculum. In this, the teaching and learning is organized around disciplines, with skills and projects interwoven. This is the recommended organizing principle for an integrated curriculum. The model indicated in Fig. 1 shows mutually supporting disciplines, with projects and skills interwoven, serving as the organizing principle. This curriculum structure promotes the learning of subject content and allows several flexible structures for integrating project work and design-implement experience.

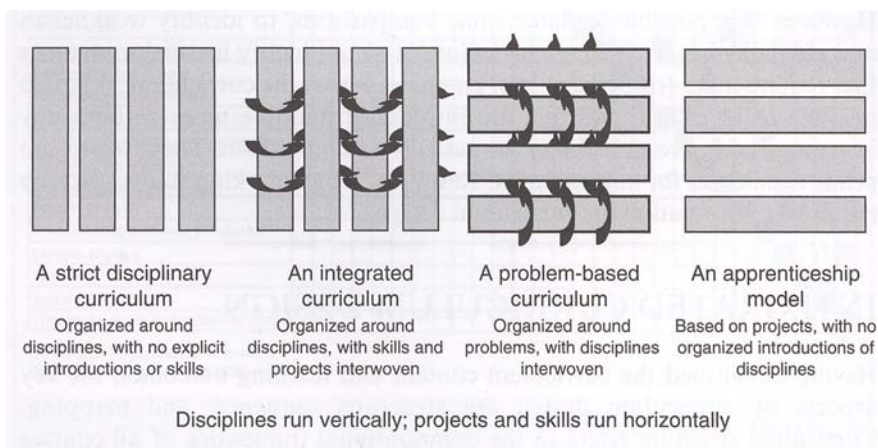


Figure 1. Diagram of an integrated curriculum compared to other alternatives [1]

Design projects and the CDIO syllabus

The semester examined in this paper is the third semester with the theme of structural design. DTU Architectural Engineering started in 2002 as an alternative to the 150-year-old civil engineering programme at DTU. The 'classic' engineering programme focuses on educating engineers to work as specialists in the final stages of the design phase, with documentation and certification, etc.

In contrast, DTU Architectural Engineering was created to educate engineers who are specialists in the early design phases of a project, where engineers traditionally play no significant role, at least as far as buildings are concerned. Design projects have been a part of DTU Architectural Engineering from the very beginning and some of the design projects could be transformed into addressing the CDIO syllabus of interdisciplinary skills. In fact, one of the design project courses that will be described in this paper was 'inherited' from the first curriculum at DTU Architectural Engineering. For several years, this design course functioned well in the integrated curriculum organization model. Its role was that of providing a combination of temporal and parallel integration. In Fig. 2, the difference between these two concepts of integration is clearly shown. The third semester structural design course ran in extension of the statics courses of the first and second semesters, and students were expected to use this fundamental knowledge in the structural designs they made in the third semester. But parallel to this, in the same semester, another more advanced statics course was run as well as a geometry course.

It was always assumed that students should also make use of the knowledge they acquired in these two courses running parallel to the design course itself.

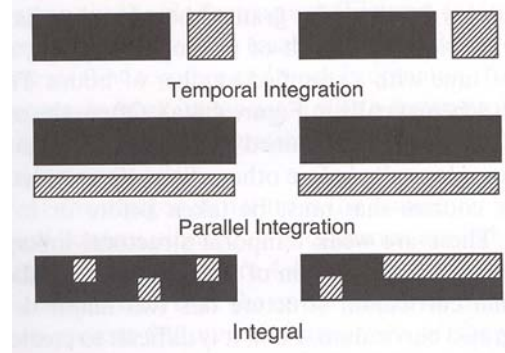


Figure 2. Before the curriculum revision, the role of the design course was that of providing a combination of temporal and parallel integration. [1]

Three years prior to the implementation of CDIO, we made an evaluation of the success of the design course as an integrated design-implement experience. The conclusion was that the design course functioned too autonomously and students could not manage to draw their engineering knowledge into the design process. Year after year, evaluations by students had constantly stated that they spent excessive amounts of time on the design course and this led to failure in some of the subject courses. So the situation was that, instead of enhancing the learning in the subject courses, the design-implement experience was disturbing the process of learning.

Although students liked the design course a lot – in spite of the above-mentioned drawbacks – the teacher team decided to work more precisely with the interface between this course with the design-implement experience and the subject courses of the semester. The discipline linkages in the semester and the curriculum were to be strengthened with a focus on achieving something more like the integral concept of Fig. 2.

The paper describes how the design course was restructured to help students integrate their previously acquired engineering knowledge in the design process as well as integrate knowledge from courses running parallel to the design project course in the third semester. This paper focuses on the integration of the design course with the geometry course, which represented a development towards a linked-merged concept (fig.3.). In the following, the two courses are first presented and then the workshop that enhanced their integration.

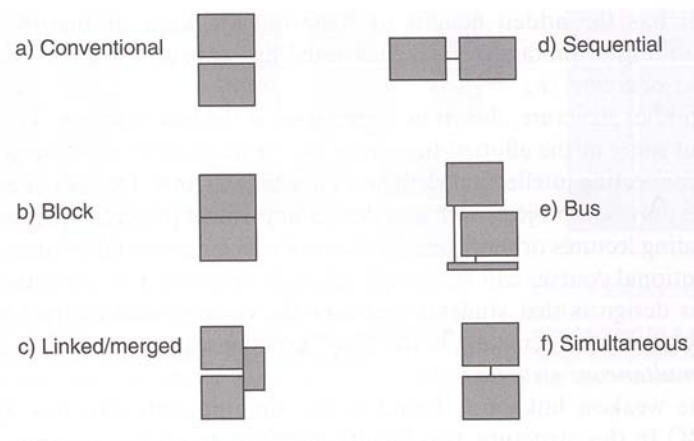


Figure 3. The integration of the design course with the geometry course, represented a development towards a linked-merged concept [1]

DESIGN PROJECT; URBAN CONTEXT AND LARGE SCALE STRUCTURES

The third semester course, “Urban context & large scale structures”, functions as the integration platform for the CDIO activities of the semester and this course hosts the design-implement experience, as mentioned above. The semester theme is structural design, and the course thus focuses on integrating knowledge from the previous and on-going statics courses.

In this course, the students are introduced to an empty place or an area of wasteland somewhere in Copenhagen. Their first task is to make a programme for a large-scale structure that will improve the place, the function of the place, and/or give new value to the place for the neighbours and the community in general.

The second task is then to design the structure. The large-scale structures proposed have been anything from large hotels, to kindergartens, road traffic plans including new bridges, pedestrian and bicycle ramps, market halls, parks, a square or a staircase, or just a wall (Fig. 4)

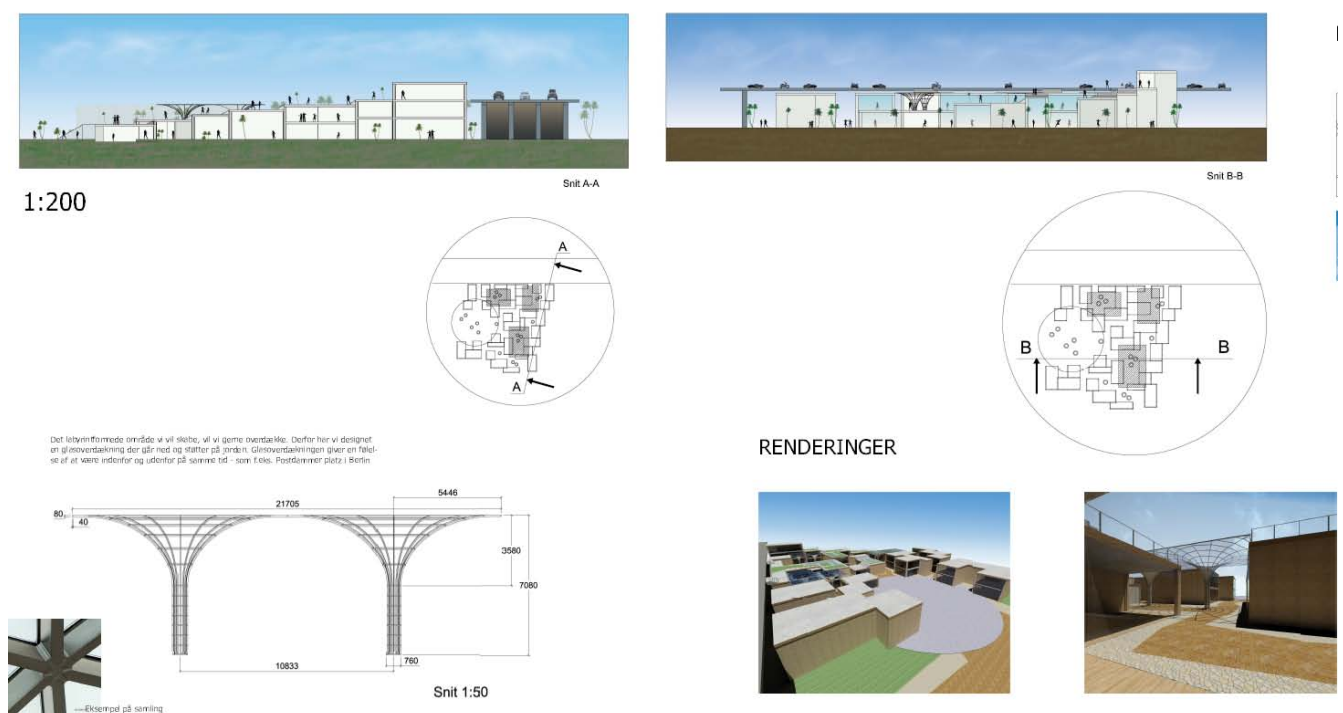


Figure 4. Student project, from the Sept-December part of the course. To the right is the existing bridge. Connecting the bridge to the run-down area below is a new shopping centre. The student project connects from existing bridge to the shunting area by means of roof gardens on a ‘Kasbah’.

The students are divided into groups. The first lecture is a short introduction to the history of the place. Then they get the most relevant documents available: maps, historic plans, etc. and they go and visit the place to register, take photos, and talk to people.

The students have to go through the process at very high speed in order to go through the learning processes that we want and achieve a result. This is done by organising the course in a series of part assignments. For each assignment, the students get a short lecture to introduce the problem area and some methods to handle it, a working period of one or two weeks and then they have to deliver. It could be a presentation, a poster, or a number of physical models.

From the semester start through to mid-October, they deliver four part assignments. Contextual analysis and narrative registration are the first two. The third assignment is the programme, and the fourth is a number of physical conceptual models illustrating the large-scale structure and some structural ideas.

After the autumn vacation, there is a two-week part assignment on conceptual structural design. The focus is on the creation of structural layouts that support the physical models and the urban context ideas behind them. The students present their concept at a workshop attended by the three teachers in urban design, structural design, and geometry in plane and space, where the final assignments for this course and the geometry course are worked out.

The groups then have three weeks to make the final proposal. In this period, they work in parallel on the geometrical assignment and the urban context large-scale structure assignment.

Structural Design

In general, structural engineering is concerned with two questions: how to form a structure to fulfil a given purpose, and how to ensure that the structure will carry the loads imposed.

Many methods have been developed for the analysis of structures and, like many other engineering schools, DTU offers a large number of courses on this issue. But in this course, the focus is on how to design or lay out the structure, and less emphasis is put on the detailed stress analysis.

Two philosophies govern the teaching. The first is that a structure can be seen as an assembly of parts and these parts can be either sub-structures or structural elements. We can call this assembly a structural system, and realize that many structural systems can meet a given requirement. Furthermore, any system and almost any structural element can be divided into sub-systems or elements; it is all a matter of scale. Nevertheless, there are a number of basic elements to which we can refer (Fig. 5).


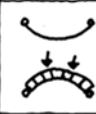
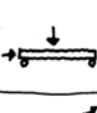
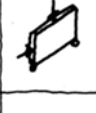




Geometry	1D	2D	3D
Stress			
1D			
2D			
3D			

Figure 5. Structural elements.

The second philosophy is that a good design is carried by a general idea, a concept. The geometry, the elements and the structural system, the materials, and the construction process should be coherent and logical both from an architectural and an engineering viewpoint.

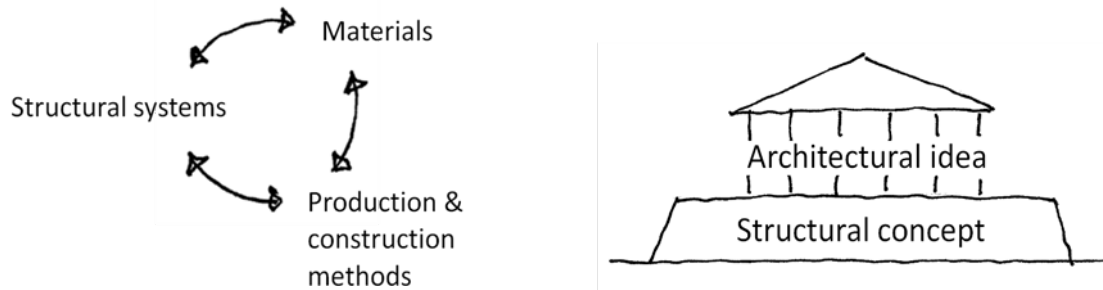


Figure 6. Structural concept.

Consequently, lectures are held on how to identify and design structural systems, how to analyse the physical properties of materials from a structural point of view, and how to develop structural concepts.

Throughout the course, emphasis is put on general design methods, such as problem-solving, intuitive or systematic generation of solutions, the use of different types of models, making experiments as well as observations, and references and other sources of information. Most of the learning is tacit because we do not teach the theory behind the methods and only briefly present the principles of the methods. The large number of part assignments simply pulls the students through the curriculum: learning by doing.

Learning objectives

Some of the learning objectives are listed below:

- To gather information about an urban situation and communicate it well
- To know basic design methods used in contemporary urban design
- To use urban design methods
- To develop and integrate concepts of building design with urban design
- To communicate graphically at a 'professional' level
- To use engineering skills for solving real-life problems
- To work conceptually on structural theory
- To use structural calculation programs in a design process
- To present structural calculations and document structural efficiency in a report

INTEGRATING THE THIRD SEMESTER COURSE IN GEOMETRY WITH THE DESIGN-IMPLEMENT PROJECT IN STRUCTURAL DESIGN.

Why a course on geometry – motivation for combining geometry and structural design

For some reason, geometry has been declining as a subject of interest for structural engineers and teaching at DTU for a number of years. This might be due to the focus on the analysis of structures. From the start, the general purpose of the Architectural Engineering programme at DTU was to produce engineers with the ability to inform the early design phases and come up with proposals for technical solutions which were relevant. In both structural and functional engineering, such solutions concern the arrangement of physical elements in space, which is why geometry should have been a fundamental teaching subject right from the beginning.

But we needed a hint from Cecil Balmond, who was interviewed by two of the authors on the occasion of the 150th anniversary of DTU BYG, to realise that we had to include a course on geometry in the curriculum. Since many of the students are more interested in the design

aspects than in pure analysis, this course also has the effect that it opens the students' minds to mathematics as an interesting tool for design and not "just" a necessity for analysis.

This is of special importance in structural design because of the very close relationship between the geometry of a structure or structural element, and the loads, section forces and stresses it can bear. The fact that you design the structural system and the section forces, and hence the volume of the structure, when you lay out its geometrical form is important information for the structural engineer and requires an interest in geometry and a basic toolbox to handle it.

The geometry course

Geometry is a natural facilitator and tool for constructive design and for structural analysis in general. In this 5-ECTS-point course, the main focus is on the design aspects – inspired and motivated by e.g. [5]. The course is essentially concerned with very basic geometric deformations of triangles and tetrahedra. The associated mappings are controlled by matrices, i.e. affine maps in plane and space, and their geometric properties are analysed using the linear algebra that the students have studied in an earlier mandatory calculus course. The design assets are enhanced further by introducing the basic geometry of space curves and by controlling the triangular and tetrahedral deformations via the Frenet-Serret basis (i.e. curvature and torsion) along the curves, see [4], [3].

So far, the course has been given twice. In 2010 it was attended by 40 students from DTU Architectural Engineering and 40 students from DTU Mechanics.

The workshop

Every student in the geometry course is offered a final credit-giving project exercise from a very general list of about 20 suggestions, see [3]. The main aim of the 4-hour workshop, which takes place just before work on the projects begins, is to focus upon, pinpoint, and perhaps also adjust a relevant choice of project for each student or group of students.

Essentially, this is facilitated in two significant ways. The DTU Architectural Engineering students are already well prepared with detailed ideas and suggestions from their previous work on their semester design project. Moreover, a number of the suggestions listed have already been exposed as appetizers during the course from the first week.

At the workshop, there are a total of 5 teachers present to guide the final choices – essentially by sheer brainstorming.

Some projects turn out to be more popular than others. Several mechanics students chose a classical roller-coaster construction problem. Some students chose to work on largely open projects, such as the Windstalks project. So far, this particular project is only a (nice) idea, see [6]. Not much is yet known about either its technological implementation or its feasibility. It is nevertheless a highly relevant case for the geometry course. It was chosen by one of the DTU Architectural Engineering groups as an integral part of their project for the design studio course and it will surely be developed further as a case study in geometry. In this way, the students are actually introducing a frontrunner resource into the future development of the course.

Another project of the same type (and with the same momentum for engaging the students as a resource) is concerned with the application of a specific piece of free software for the optimization of geometric structures, see [2].

Out of the 42 Architectural Engineering students who participated in the course during the autumn of 2010, all except 8 chose a geometry project which was a direct spin-off from their Semester design project. The 8 chose a roller-coaster construction project and a tall building construction project, respectively, both of course related to architectural engineering, but not directly related to their specific design projects.

The workload of the teachers involved in the workshop, therefore, is mainly to take an active part in the workshop and to act afterwards as consultants for the students in those cases where they have specific questions concerning the topics of the teachers' expertise. Each consultancy window (of typically 1 hour a few days per week during three weeks) was

divided into blocks of 15 minutes, which could then be 'booked' by the students via e-mail. It was also possible to ask more technical questions (typically related to the application of Maple) via e-mail with attached worksheets containing the problem pointed out and formulated as clearly as possible. This functions very well – not least because of the precise, focused, and well-prepared communication which is necessary because of the limited time available for each consultancy block.

A general evaluation comment by students

"The collaboration between the geometry project and Design Studio Course was really great. It gives a feeling for the possible applications of geometry in architectural design – which is very useful, for example, if I get employment at a drawing office."

CONCLUSION

The goal of realizing an integrated curriculum and having a design-implement experience integrated in the semester was, if not totally achieved, then at least significantly approached by means of the almost banal 'tool' of a 4-hour joint workshop.

The linked or merged structures are when two faculty members start the term teaching independently, and at some point the two courses flow together and work in common. [91] Students cannot manage to integrate their technical scientific knowledge in the design project at this early stage in their studies by themselves. The joint workshop helped both teachers and students in realizing the design potential of the geometry course.

Linkages within a curriculum place demands on faculty staff because they require substantial cooperation and adjustment in course content in order to achieve the desired connections. The 4-hour joint workshop proved to be a very efficient way for faculty staff to achieve these linkages.

Although the curriculum is fixed for the first 4 semesters in this programme, there are always students who need individual curricula. The 4-hour joint workshops enable us to maintain flexibility in the elective curriculum. If the students do not have the geometry course, they do not need to attend the workshop and will not integrate geometry aspects in their design projects. And if they do not attend the design course, the geometry teacher has report themes they can choose that are independent of the design course.

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DELFT AEROSPACE ENGINEERING INTEGRATED CURRICULUM

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ABSTRACT

The complex multidisciplinary problems and challenges in our society require deep problem solvers in science, management and engineering who are also capable of interacting with and understanding specialists from a wide range of disciplines and functional areas. Industry refers to these people as T-shaped professionals. The T-shaped professional model has been the reference for the bachelor and master curricula in Aerospace Engineering at Delft University of Technology. The bachelor provides the broad academic background in the domain of aerospace engineering. The life cycle of the engineering process and contextual storylines of famous persons in aviation, aeronautics or space form the cement and thread for the themes of the bachelor curriculum. The bachelor develops the academic intellectual skills and attitudes to analyse, apply, synthesize, and design, and prepares for the master. The master programme aims to develop the basic competences acquired in the bachelor to a higher level in terms of knowledge, critical reflection, making judgements and working independently. While “engineering and design” is the central theme of the bachelor, “research” is the theme of the master. This curricular framework gives the bachelor and master an own profile and identity. They use state-of-the-art content that is interwoven with thematic design projects and trainings for personal and system building skills, using international standard text books, up-to-date teaching methods, excellent facilities, with a focus on the aircraft and spacecraft throughout the programmes. Excellence programmes are available for the top 5 percent students in both bachelor and master. In these honours classes self-regulated students define their personal learning objectives and levels to be attained. Their key concept is that of open-ended learning and autonomy. In the bachelor the excellence programme substitutes design projects in the regular curriculum by one ambitious and compelling project with a high societal relevance and visibility. In the master it is a half-year add-on programme about taking the lead in the creation and operation of new products, systems or processes, and developing awareness and understanding of the importance and strategic impact of research and technological developments on society.

KEYWORDS

Integrated curriculum, T-shaped professional, aerospace, engineering education

INTRODUCTION

“To be the best Aerospace Engineering Faculty in the world that inspires students, staff and society with modern education and ambitious research of the highest quality for the future of aerospace”. That is the mission of the Faculty of Aerospace Engineering of TU Delft, so the goal is to attract, excite and educate students to become highly qualified engineers, and equip them with the knowledge, creative and communication skills that are needed in the

globalising and changing society. Therefore the education is set in the context of the practice of engineering, design and research in aerospace engineering. It allows the faculty to showcase its areas of expertise and gives students the flexibility to choose experience that aligns with their interest.

THE CONTEXT

The Faculty of Aerospace Engineering of TU Delft has a reputation for excellence in education. With about 1650 bachelor and 650 master students the faculty is number one in the Western world of aerospace engineering education. The faculty works closely with industry and research institutes and covers almost all technical and societal issues related to aeronautical and space engineering, design and operation. Besides the disciplines that are directly related to aerospace vehicles, the faculty covers the use of spacecraft for planetary sciences and astronomical exploration, and wind energy as a spin-off from rotorcraft aerodynamics.

Aerospace engineering is associated with challenges, difficulty and complexity. As the bachelor curriculum relates to the aerospace domain from the first study year onwards, it is appealing (“rocket science”) for young people, attracts freshmen students with high grades for their secondary education and is a favourite study for talented students with high ambition and strong motivation. The bachelor and master are fully taught in English so that 30% of the students are international and come from all over Europe, India and China. They bring the international spirit to the programmes and create a stimulating environment. This international character matches with the needs of aerospace industry for graduates with a global mindset and an awareness of cultural diversity.

THE PROFILE OF THE GRADUATES

The complex multidisciplinary problems and challenges in aerospace engineering require deep problem solvers in science, management and engineering who are also capable of interacting with and understanding specialists from other disciplines and functional areas. Industry refers to these people as T-shaped professionals (Figure 1). These professionals have enhanced skills in problem-solving, creativity, talent, intelligence, and the ability to perform complex work.

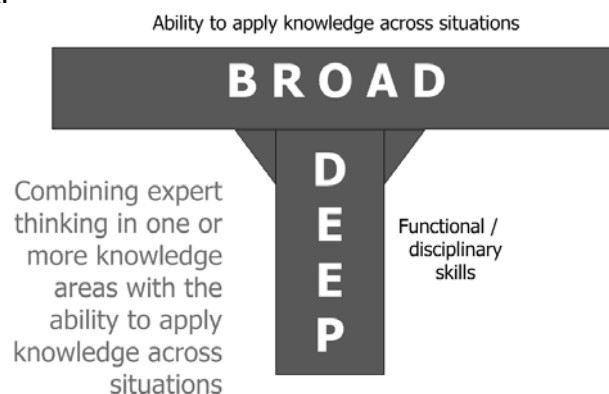


Figure 1 The T-shaped professional

Many industries and institutes look for young graduates who have the potency to develop into (top) management or specialist functions. Recruiters consider the successful completion of a master programme of high standards with a good reputation as the proof of excellence for potential top managers and specialists. The discipline of specialisation is less relevant than the fact that the candidate has demonstrated steep learning curves and proven his

competence to master a deep working knowledge in a multidisciplinary field of high complexity. Aerospace engineering is such field. Mastering a deep working knowledge of fundamentals in a high tech environment has thus transformed into a selection criterion for top functions in the professional environment.

The graduate of the master programme is a Master of Science Aerospace Engineering. He is an academic professional who applies his knowledge and skills to solve practical problems. It is therefore of crucial importance that the authentic and relevant problems in the life of an engineer are also present as identifiable subjects in the bachelor and master curricula. Students have to learn how to analyse and solve such practical problems. This requires knowledge and the skills to listen and present, delegate, argument, negotiate and convince, criticize and accept critics. Since most engineers work in project teams, they have to be able to share their minds, and be flexible to accommodate their work to team insight and performance.

The educational programmes have to meet all these demands and offer students the opportunity to gain in-depth working knowledge in aerospace engineering sciences and qualifications in the interdisciplinary requirements, complemented with social and organisational skills so that all graduate engineers are capable of combining expert thinking with the ability to apply knowledge across situations.

REASONS FOR A RADICAL CHANGE

The bachelor and master degree programmes have been highly rated by students and exchange visitors since many years, and by the international accreditation committees who review the degree programmes every other six years. It is natural thing that external pressures and incremental changes lead to increasingly incoherent and overstuffed curricula. Curricula lose part of their profile and structure and, particularly in the master, tend to deteriorate into a series of specialist courses with little coherence. Also the learning and teaching environment change: today's students have different styles of learning, graduates need different competences in their jobs than ten to fifteen years ago. New pedagogical methods have been developed.

In 2006 faculty management realised that the above issues also evolved in the curricula of aerospace engineering and would not be mitigated by a gradual stepwise improvement. It was decided to go for a major overhaul and make a radical change in the bachelor as well as the master programme, making them more coherent, balanced, synergetic and compelling. September 2010 the bachelor and master innovation and development phases were completed and students were transitioned to the new programmes.

THE STAKEHOLDERS

To determine the profile, content and teaching methods of the upgraded bachelor curriculum the input was used from various stakeholders like society, industry and institutes, university, faculty, lecturers, pedagogical experts, and last but not least students, who are the customers, co-producers and product at the same time.

The current generation of students is enthusiastic, idealistic and inspiring, and familiar with powerful tools like computational, communication and search engines. They are strong in interacting, networking, communicating. They often miss the context of societal, business and political relevance to what is being taught, and hardly know what engineers do. At the university these students are immersed in a research environment in which engineering sciences and expert design are taught. This is an important concern because it is well known

that engineering students learn differently than research oriented students. Engineering students want to see the practical use before the theory, learn from the concrete to the abstract by touching, taking apart and putting together. They discover first and learn on demand. Students in fundamental sciences like mathematics and physics primarily learn from the abstract to the concrete via the path of equations, theory, and analysis. For both types of students the road to understanding and motivation to learn the theory, comes through applications and connections to real-world problems.

Surveys under alumni and the professional field have shown that prospective employees have not only to learn to solve the problem right, but also to solve the right problem. The curriculum therefore should complement the teaching of knowledge and understanding in aerospace engineering sciences by transferrable skills in team work, communication, management and system-building engineering.

THE CURRICULAR FRAMEWORK

The T-shaped professional model, discussed above, is an important reference for the bachelor and master (Figure 2). The bachelor provides the broad academic background with consolidated knowledge of aerospace engineering, and the development of academic intellectual skills and attitudes to analyse, apply, synthesize and design, and a critical attitude, and communication skills, and an awareness of the scientific and societal context. The bachelor prepares for a wide range of national and international master programmes. It does not prepare for the job market because that market does not exist for BSc graduates. Industries and institutes either recruit academic Masters of Sciences or professional Bachelors of Engineering (undergraduate degree in professional higher education at a vocational university). The master provides the expert view in aerospace engineering and focuses on detailed knowledge of one or more subdisciplines together with academic intellectual skills and attitudes to model, analyse, solve, experiment and research: The master completes the education to the all-round aerospace engineer. This framework gives the bachelor and master an own profile, an own identity, and is fully in line with the Bologna Treaty's educational requirements and curriculum standards of the two-cycle bachelor master structure.

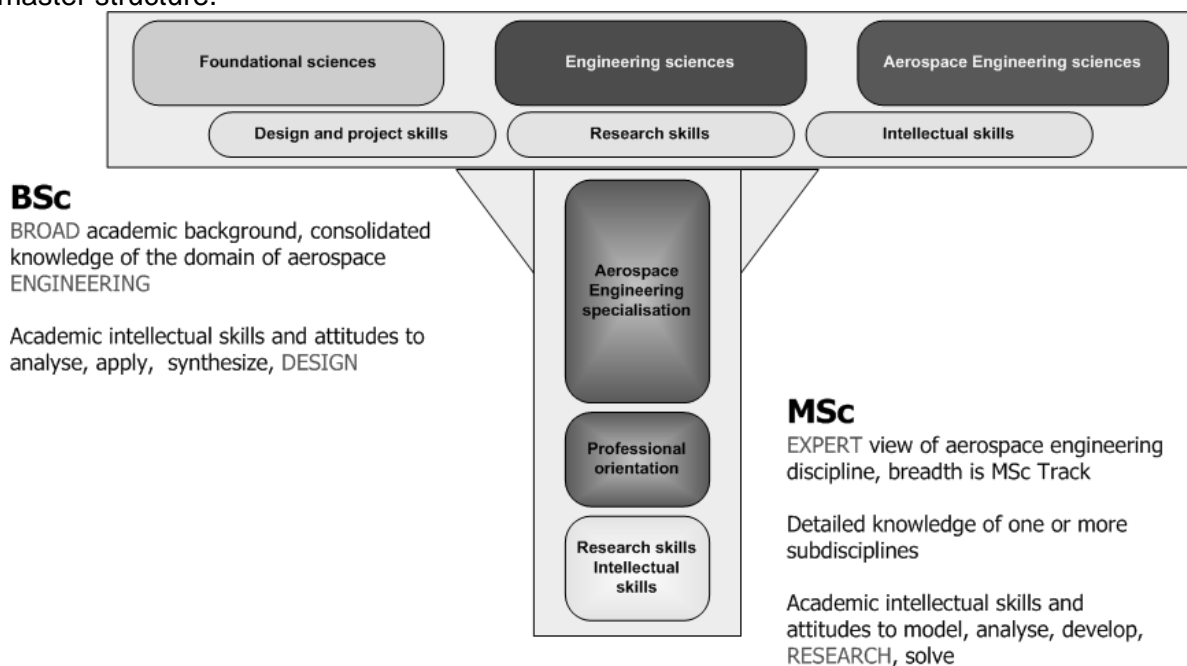


Figure 2 The T-shaped professional as reference for the bachelor and master programmes

For the bachelor and master programmes the eight touchstones are:

1. Knowledge, skills, practices and values found in engineering, design and research work in the field of aerospace engineering are reflected
2. Technical fundamentals, set in the context of engineering, designing, building and operating aircraft and spacecraft, are leading (core knowledge in engineering work, key problem solving strategies)
3. Disciplinary courses are interwoven with learning activities that develop personal, professional and system building skills
4. Students are exposed to experiences that are representative for their future profession of aerospace engineer or scientist (professional roles in projects, authentic real-life cases, design-build-test and research learning experiences)
5. Individual assessments assure that each student attains the required levels in knowledge, skills and attitude
6. Differentiation in the programmes is available in both programmes and provides opportunities for broadening or specialisation
7. Talented students are challenged by dedicated honours programmes in which autonomy and self-directed learning are the key attributes
8. The aircraft and spacecraft are the central objects of study

PROFILE OF THE BACHELOR

The bachelor programme is implemented as follows:

- “Object-oriented learning”: shaped around the engineering, design and operations of aircraft and spacecraft
- It has a thematic structure that represents the life cycle of an engineering process
- It has a learning-by-doing (-together) approach and makes use of state-of-the-art learning materials like E-books and active learning methods to apply theory and consolidate knowledge.
- Its constituents are mostly multidisciplinary courses in which the teaching staff from different chairs collaborate to achieve a broad and consolidated knowledge of engineering sciences applied to aerospace engineering
- It trains the students explicitly in the development of academic skills; in the first year focusing on study planning; in later years on autonomy and self-directed study
- It achieves a social integration of the students in the faculty.

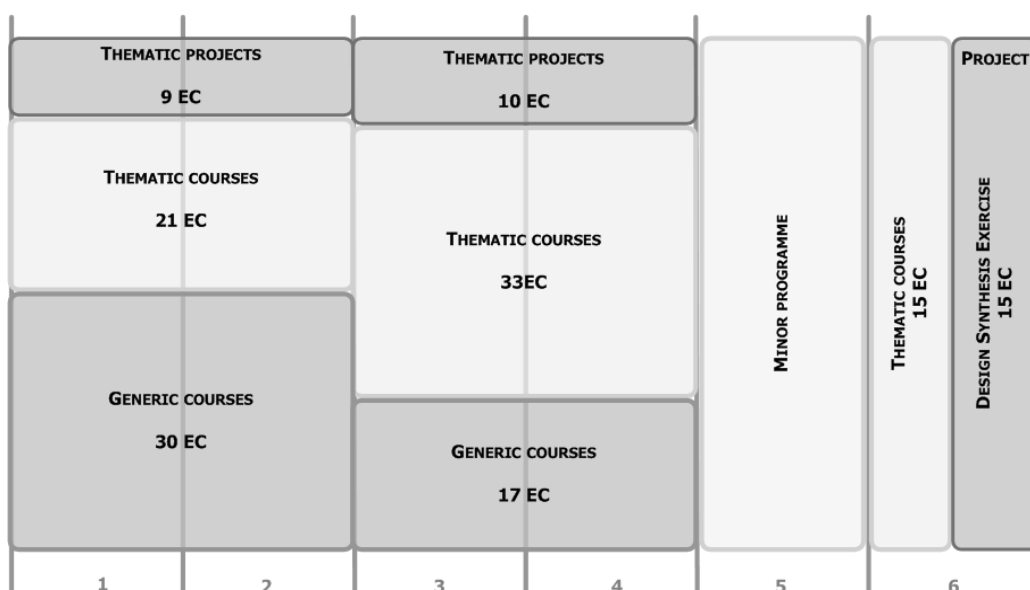


Figure 3 Schematic of the curricular structure. Each semester most thematic courses are “linked” to the thematic project to provide an integrated student experience

The thematic structure assures that the experience students achieve from one semester to the next forms a coherent whole: the thematic projects and courses from one semester are connected through lines of advancement in both knowledge and skills. In the first semester, students are introduced to the many aspects of aerospace engineering in an exploratory fashion through an introductory course with project that provide the student with the “big picture”, the framework for the practice of engineering, the context for his study in the coming semesters. In the following semesters students mature along the disciplinary lines of advancement and encounter multiple experiences in open-ended design projects, lab work and trainings. This combination provides the opportunity to develop depth and sophistication over time. This arrangement helps students transition from a more concrete perspective on engineering sciences to one that integrates both the concrete and abstract concepts. Thus the students develop, practice and build up the knowledge and skills they need to succeed in the final project of the bachelor, the Design Synthesis Exercise, as the stepping stone to the master programme.

A CURRICULAR STRUCTURE WITH A STORY

At its core any curriculum is fundamentally about something. The Faculty of Aerospace Engineering emphasises its “object-oriented” curriculum, which is fundamentally about how one engineers aircraft and spacecraft. The curriculum tells this story. The organisation retains the “object orientation” by focusing on the kinds of roles and activities that aerospace engineers fulfil during the different phases of an aerospace engineering project (Figure 5). Initially, any engineering project requires exploration of the problem space: What is the context of this project? What do the requirements really mean? What solutions already exist? This is then followed by conceptual design and detailed design: What kind of structure should we build? What are the subsystems involved, and how do they interface with each other? How should we document it? Real engineering problems require extensive analysis, modelling, and testing, verification and validation in the end: What experiment should we run? How can we model the system? How do we evaluate and prove the proposed solution?

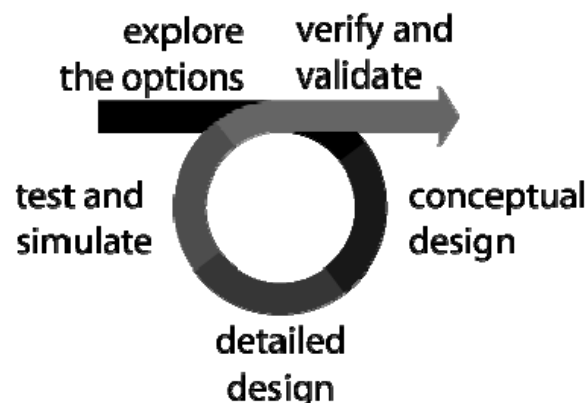


Figure 5 The phases of an engineering design process form the themes of the five semesters

This series of phases provides the themes for the curriculum each semester (Figure 6). The first semester focuses on exploration of the aerospace domain. It includes a project in which the first design-build-test experience is a concrete experience the student can reflect upon. It is complemented and followed by an exposure to theory and abstractions in the thematic courses. In this project the students investigate the concept of a flying wing, do their first aerodynamics back-of-an-envelope analysis, design the aerodynamic profile, shape it, manufacture it, test it in a wind tunnel, analyse the results and iterate the design, fly the wing in a competition. Also the spaceflight perspective is addressed by analysing how the wing should look like to fly in another planetary atmosphere. The second semester focuses on conceptual design. Since engineering students learn best from the concrete to the abstract,

this project is shaped around the design, construction and testing of light-weight structures. It makes use of the faculty's model collection of aircraft and spacecraft systems and the materials and structures lab test facilities. The third semester project about system design addresses the higher and more abstract level of the designing major aircraft or spacecraft systems, considering the different disciplines of aerodynamics, flight mechanics, structures, materials, spaceflight and aerospace design methods. It takes the interfaces to the overall system into account using various simulation models in a Matlab environment. Drawings are made in CATIA, a commercial Computer Aided Design software suit frequently used in aerospace industries. The fourth semester's theme focuses on abstracter analysis, modelling and simulation, and use of authentic noisy measurement data. Last but not least the first half of the last semester the framework focuses on verification and validation, using advanced simulation models of structural behaviour and flight dynamics and in-flight measurement data. The project integrates multiple topics from the semester. Students report the outcome of this research oriented work in a scientific paper. Finally, all five themes are synthesized in the Design Synthesis Exercise. This capstone project provides the opportunity to apply all theory and build the students' confidence in engineering.

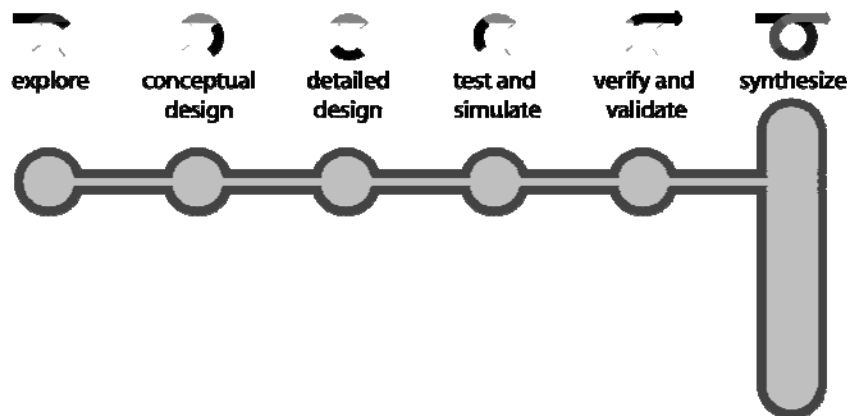


Figure 6 The themes for the semesters

The themes provide the “boundary conditions”. They define the types of activities and roles students undertake during the semester, neither their specific context nor content. Within these boundary conditions, the expertise and passion of the staff have resulted in compelling projects. They provide a concrete, authentic context for student's work – students not just learn the theory; they use the theory in cooperation with young researchers, so that they develop an appreciation for what the theory means in practice.

LEARNING AND TEACHING METHODS

Active learning is based on a simple proposition: people retain more information if they are actively involved in using information (Figure 7). Studies show that passive approaches (e.g. listening to a lecture, watching a demonstration) yield retention on the order of 20-50%, while active approaches (discussing an idea, solving a problem, writing a simulation) yield retention of 70-90%. In brief, active learning is any approach that engages students in using the material they are learning. Both staff and students have to get used to the active attitude that is expected. For courses with an instruction format like lecturing, instruction or application session the in-class time is constrained to 30%. This leaves sufficient time for self-study. For deep learning a consolidation of knowledge is required, which takes significantly more time than just the acquisition of new knowledge.

Active learning is broader than project work. It encompasses a broad spectrum of teaching methods, ranging from 1) “interactive engagement lecturing techniques” which are practiced in a large lecture, via 2) “studio classroom sessions” where students get short instructions

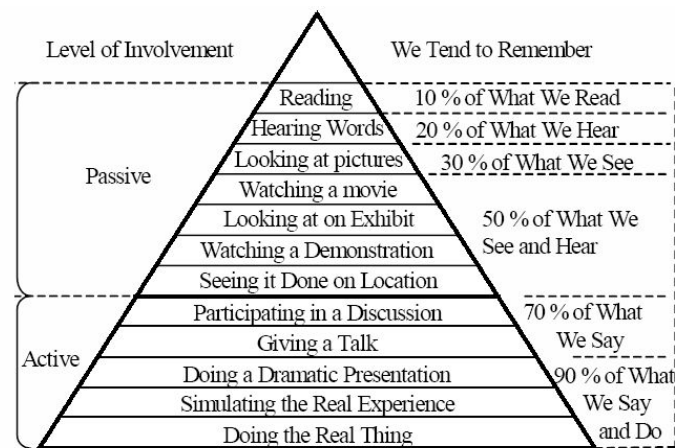


Figure 7 The pyramid of learning

and individually or in small groups do computer-based work in real time, to 3) online homework systems in which students have access to self-paced tutorials that provide individualised coaching with hints and feedback specific to individual misconceptions.

The choice for teaching, learning and assessment method has been aligned with the learning objectives, pedagogical approach and available resources (Figure 8). Most courses in mechanics, physics and engineering make use of state-of-the art commercially available study books with accompanying software applications, thus minimising development or maintenance cost.

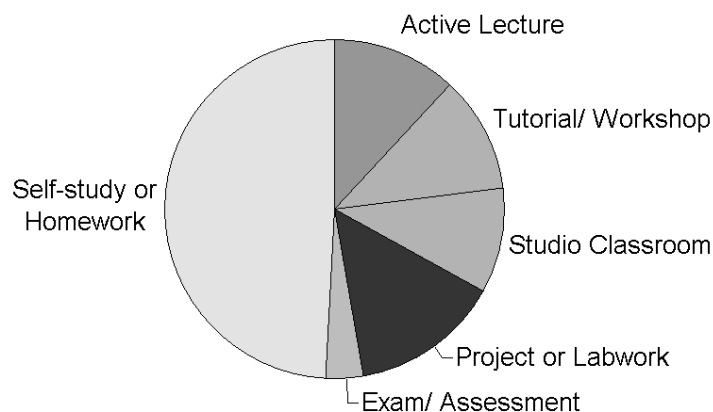


Figure 8 Distribution of teaching and learning methods in the first year

A STRONG BACHELOR GRADUATE

The thematic projects contain trainings on intellectual and communication skills, and have explicit relationships between courses, so that students have the opportunity to consolidate, synthesize and apply their knowledge every semester, rather than simply during their last ten weeks of the bachelor (Figure 4). The thematic structure enforces the students throughout the curriculum to practice the various components of an engineering project. So when students enters the Design Synthesis Exercise project, he will be repeating a cycle that he has already experienced, and he will be refining skills of project management, teamwork,

reporting an presentation he already learnt and practiced earlier. Thus the bachelor graduate has learnt to appreciate the engineering process, to contribute to the development of new engineering products and systems, while working in an engineering environment.

PROFILE OF THE MASTER

The master completes the educating to an all-round aerospace engineer. The programme aims to develop the basic competences acquired in the bachelor to a higher level in terms of knowledge, critical reflection, making judgements and working independently. Specialisation is necessary to achieve the higher attainment levels, and therefore students narrow down into a field of expertise in aerospace engineering. While “engineering and design” is the central theme of the bachelor, “research” is the theme of the master.

The master programme has the following salient features:

- The student develops a thorough and detailed knowledge of one identifiable field of expertise in aerospace engineering
- The student has sufficient flexibility and autonomy in composing and planning his individual study programme (self-directed learning)
- The student acquires professional skills in a three-month internship
- Transparent quality assurance procedure for thesis project

At the start of his master, each student chooses a particular field of aerospace engineering (Figure 9). In this field he composes his individual study programme of obligatory and elective courses, a Master Orientation Project or Literature Study, an internship and the concluding thesis project. The obligatory courses develop the expert view of the student. The elective courses offer the flexibility to meet specific interest in a specialisation in subfields of expertise or add multi-disciplinary elements, repair deficiencies or add personal interest. The elective courses are selected by the student in consultation with the professor.

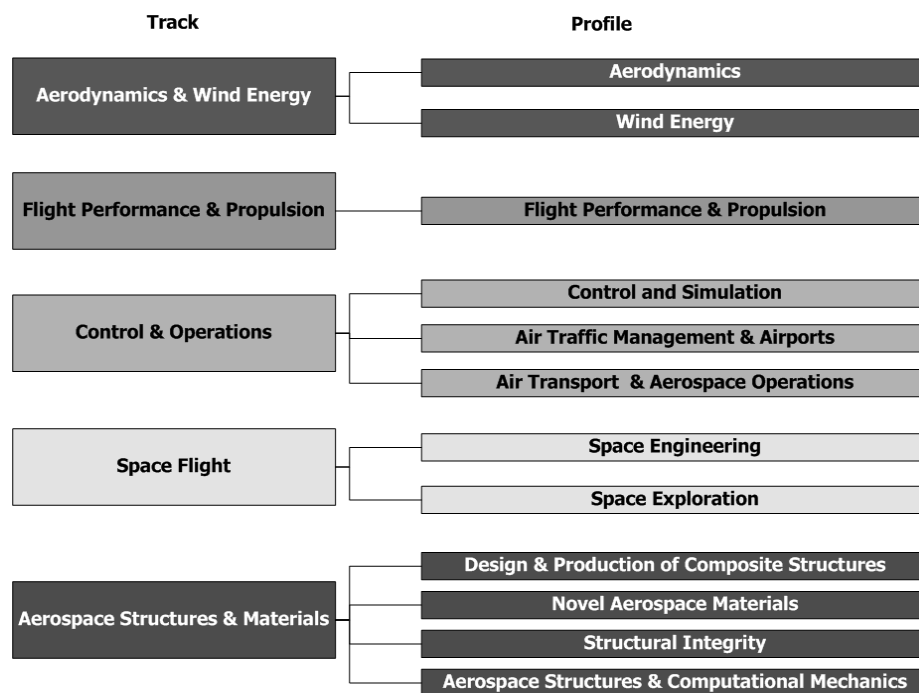


Figure 9 The available specialisations and subspecialisations in the master

Each individual programme (Figure 10) contains a Master Orientation Project or a Literature Study. The Master Orientation Project is primarily for students who do not want to develop into a researcher but an engineer. Its objectives are familiarising in a field of expertise and getting a sneak preview of what it means to perform independent research or expert design type of work on a day to day basis. The project prepares the student for the choice of the subject of his thesis. The Literature Study is a preparatory research in direct relation to the second-year thesis subject, with the aim to achieve maximum depth in the thesis later on. Both the Master Orientation Project and Literature Study address and practice the theory about doing research that is taught in the obligatory course Research Methodologies. This course focuses on the key questions what research is and how to systematically perform scientifically correct research, which research methods exist and what can be the differences and similarities in research projects. The student learns how to establish a research plan. This is the first step to be taken at the start of the thesis project, a step many students have found difficult to take in the past.

The internship is a key element in the master is highly appreciated by students, alumni and the professional field. It allows the student to experience the professional environment, develop organisation sensitivity, and make an active contribution to aerospace related industries or research institutes. It exposes students to a real work environment for a period of 12 weeks on a full-time basis. About 80% of the students take an internship abroad, adding to the international character of the programme.

It is a “learn and explore” kind of internship, enabling students to acquire professional skills different from those taught in the programme. Beside the company assignment, the internship has a dedicated assignment about the engineering profession and a personal reflection on performance in the internship. The assignment about the engineering profession is a search in the company about how well the company meets professional standards in respect of topics like sustainable development, project or risk management, value management, health and safety management. Another dedicated assignment about the personal reflection on performance is about the student himself, where questions are addressed such as: What did I learn about myself in the professional working environment? Did I discover unsuspected talents? Which points for personal improvements remain?

CORE COURSES	PROFILE COURSES	ELECTIVE COURSES	LITERATURE STUDY	INTERNSHIP 18 EC
»15 EC	»17EC	14 EC	12 EC	MSC THESIS PROJECT 42 EC
No choice	No choice	Choice in consultation with Profile Coordinator	+ RESEARCH METHODS 2 EC	

Figure 10 Standard outline of the Master Aerospace Engineering

The master is concluded by the thesis project, an in-depth research or expert design project in the field of expertise the student has chosen. A student chooses to take an in-depth mono-disciplinary thesis project or link his thesis to a multidisciplinary project that runs with contributions and support from other research groups. The thesis project then has its main point in one specialisation but crosses over with another one.

DIFFERENTIATION AND EXCELLENCE

Today's job market is calling for engineers with wide-ranging knowledge who are willing to look beyond the boundaries of their own degree discipline. The major/minor system in the first semester of the third year of the bachelor enables the student to add another dimension to his study in the form of a minor. The minor programme is a cohesive package of third-year courses on academic level about a subject of personal choice, which may be a technical, managerial, economical specialisation, or general topics of contemporary liberal arts.

An important facet of making the curriculum compelling has been to accommodate differentiated levels of ambition and interest of the individual students. Some elements of the curriculum should therefore offer a level of adaptability to the preferences of interest and ambition level of the students through "outcome-based" education, i.e. by offering curriculum elements that challenge ambition or content levels students can choose from. These elements are not per a curriculum of subjects students have to know, but rather based upon the student who decides what is important for him to learn. For the 5% highly talented and most ambitious bachelor students the AExcellence programme provides these students with the opportunity to link learning to personal interests and goals. The programme is for self-regulated students who define their personal learning objectives and levels to be attained, who attempt to monitor, regulate and control their learning process, motivation and behaviour. The AExcellence programme is embedded in the regular bachelor and concentrates on one ambitious and compelling theme each year with a high societal relevance and visibility, and consequential strong interest from students, faculty and audience. Potential subjects are a totally new and environmentally-friendly aircraft concept, the development of personal air transport (such as flying taxis and cars), an intensification of the search for alien life, a start on colonizing space or diverting dangerous asteroids. The AExcellence programme is an interesting nursery garden of talents for prospective master and potential PhD students.

In the master TU Delft offers a supplementary Honours Track programme for its ambitious master students with an excellent track record. The programme offers the opportunity to attain a higher level of personal development by broadening or strengthening the skills young scientists or professionals need in aerospace engineering. The half-year study programme comprises two obligatory courses on ethics and creativity in engineering. The remaining 70% is an individual programme that is defined by the student on the basis of personal learning objectives that should be related to taking the lead in the creation and operation of new products, systems or processes, and developing awareness and understanding of the importance and strategic impact of research and technological developments on society.

NEXT STEP

Much of the thinking that has driven today's bachelor and master programmes will probably remain valid for the next decade. Also in future aerospace engineering will reach across disciplinary boundaries. Therefore the curricula do not and should not restrict themselves to disciplinary silos. The pace of technological change accelerates, expertise knowledge is volatile. A curriculum that emphasises the fundamentals is therefore more valuable. The graduates must be prepared to predict, create, and manage the technologies of the future, not simply respond to the technologies of today. They must not only have a superb command of engineering fundamentals, but also a broad perspective regarding the role of engineering in society, the creativity to envision new solutions to the world's problems in the domain of aerospace engineering and beyond.

CONCLUSION

This paper has presented the framework of the Delft Aerospace Engineering integrated bachelor and master curricula where acquiring disciplinary knowledge, its application in lab work and authentic projects is interwoven with the development of academic skills like communication, design and research.

The bachelor and master have an own profile and identity. Engineering and design are the central themes for the bachelor, research and specialisation for the master. The bachelor curriculum has a well-structured knowledge base in a motivational context of aerospace engineering themes and hands-on projects and experiments, where learning-by-doing-(together) creates good interaction with others and an atmosphere of collaboration.

Although the faculty was unfamiliar with the CDIO approach when writing and executing the blueprint for the innovation of the curricular framework, the development process and the bachelor curriculum are very much in line with the CDIO approach and meet many of the CDIO Standards.

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A Course on Applied Superconductivity Shared by Four Departments

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ABSTRACT

In this paper a course on applied superconductivity is described. The course structure is outlined and the learning objectives and the learning activities are described. The teaching was multidisciplinary given by four departments each contributing with their expertise. Being applied superconductivity the focus was on an application, which could benefit from using superconductors. The application used in this course was superconducting generators for direct drive wind turbines. As part of the course the students built a small-scale superconducting machine and set up finite element models of that machine as well as large-scale wind turbine generators with superconductors and also permanent magnet generators. The course was assessed by a student conference contribution and reports from the students. The quality of the course was evaluated by interviewing the students after the course had finished. The students were very pleased with the course and gave suggestions of how the course could be improved further.

KEYWORDS

Electrical Machines, Mathematical Modelling, Project Based Learning, Superconductivity, Wind Energy.

INTRODUCTION

The need for engineers that can conceive, design, implement and operate (CDIO) in the interdisciplinary environments has been pushed by both industry and governments in recent years. This need is being answered in part by academia, by focusing more on interdisciplinarity in the learning process of engineering students [1], [2] and by active

learning initiatives, such as the CDIO initiative [3]. It could be argued that interdisciplinarity in engineering is the obvious route to go, as most engineering problems in their very nature are interdisciplinary. Teaching interdisciplinary courses has, however, also received much attention outside of the engineering disciplines over the last of decades [4]-[7].

This paper presents an interdisciplinary course taught at the Technical University of Denmark [8] as an intensive three-week course in June 2010, as part of the Grøn Dyst (Green Match) initiative [9]. The course was shared between four departments, namely the Department of Electrical Engineering, Mathematics, Physics and the Materials Research Division at Risø DTU. The course was on applied superconductivity and focused on superconducting electrical generators for wind turbine applications.

SUPERCONDUCTIVITY

Superconductivity is an area of physics that requires a thorough understanding of thermodynamics, electromagnetism, material science and quantum physics [10]. Applied superconductivity focuses more on the component that superconductivity is applied to, e.g. electrical machines [11], MRI scanners [12], fault current limiters [13], electrical power cables [14], and does therefore not necessarily require the same thorough foundation in theoretical physics.

In applied superconductivity it is more important to understand the macroscopic characteristics and the constraints of the superconductors, rather than the details of the interaction between the electron pairs making up the superconducting condensate inside the materials. Superconductors have the unique ability to exhibit practically zero resistance under certain operating conditions. These conditions can be divided into three: first, the temperature (T) has to stay below the critical temperature (T_c); secondly, the flux density (B) must be below the critical flux density (B_c); and finally, the current density in the superconductor must stay below the critical current density (J_c), see figure 1. The critical current density is dictated by the ability of a superconducting material to prevent the movement of circulating supercurrent flow patterns called flux lines, which are created by a magnetic field applied to a superconductor. Thus the critical current density is a function of both temperature and applied field $J_c(B,T)$. The flux lines inside the superconductor will gradually start to move as the critical surface in figure 1 is approached and local heating will result causing a fast suppression of the superconducting state. One of the challenges of building a superconducting machine is to ensure that the critical surface of the conductor is not exceeded in any part of the field winding coils.

As superconductors exhibit practically zero resistance under the right conditions, these are ideal for applications where large electric currents are advantageous. One such application, where superconductors could become commercially viable in the future is high temperature superconducting (HTS) wind turbine generators, where the HTS is used to establish the main magnetic field from the rotor. Such applications have been proposed by industry [15] as well as academia [16], where the argument is that if a higher magnetic airgap flux density can be achieved by employing HTS, a smaller machine that delivers the same power may be constructed. The argument is based on the knowledge that the power produced by an electrical machine is the product of the rotational speed of the machine and the torque. The latter of which is proportional to the electric loading (the amount of current in the stator per meter circumference), the airgap flux density and the size of the machine. Therefore if the airgap flux density can be doubled, then the size of the machine can be halved.

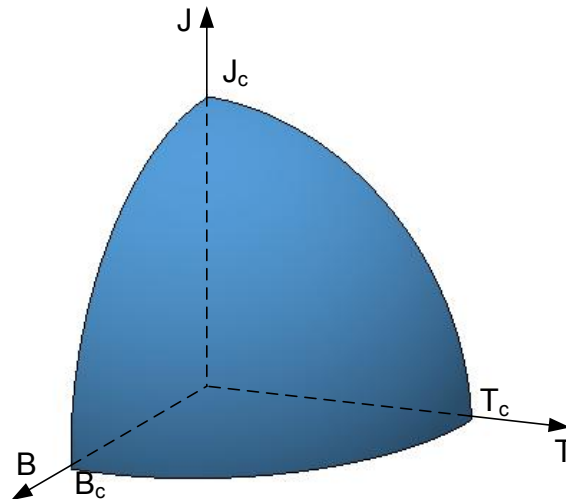


Figure 1. Surface of critical temperature, critical current density, and critical flux density.

COURSE STRUCTURE

The course was given as an intensive three week course, where the students only focused on this particular course. The course was shared by four departments: Electrical Engineering, Materials Research Division, Mathematics, and Physics, all with their own area of expertise. The course attracted 9 students, all of which, except for one, had a thorough understanding of electrical machines before starting the course. The students were from 3rd and 4th year, meaning the some were final year bachelor students, whereas others were first year master students. All of the students had followed previous project based courses.

The beginning of week one was dedicated to supplementing the student's knowledge of superconductivity, wind energy, mathematical modelling of superconductors, and finite element (FE) modelling of electrical machines. The rest of week one, week two, and the beginning of week three, was spent in groups, where one group modelled a permanent magnet (PM) wind turbine generator to use as a reference for the HTS wind turbine generator; one group designed and modelled a large scale HTS wind turbine generator; and one group modelled and built a small scale HTS machine demonstrator. The end of week three was spent preparing a poster presentation, a short report per group, and a video presentation of the built HTS machine demonstrator. The course assessment was by pass/not pass, and was based on the output from the students, i.e. the reports, the prototype demonstrator, and the poster presentation at the Grøn Dyst student conference at DTU.

LEARNING OBJECTIVES AND ACTIVITIES

The learning objectives in this interdisciplinary course can be divided into three levels, where each level and the associated activity are explained in what follows.

Basic Knowledge and Background Understanding

The students were introduced through lectures to the theory behind superconductivity; the argument and push for offshore wind farms; and the mathematical modelling of superconductors. These three lectures were given in the beginning of the course and gave

the students a chance of understanding the argument for offshore superconducting wind turbines. The basic argument is briefly summarized here. The trend in the wind energy sector is to place the wind turbines offshore. The reason for this is that planning permission for onshore wind turbines has become difficult to obtain in the areas where the electricity is consumed, and that the wind turbines are better utilized offshore where the average wind speeds are higher than onshore. Being offshore, the installation costs per unit are high and the wind turbines are difficult to access for maintenance. This calls for more reliable and larger wind turbines. However, as the wind turbine size increases, the weight increases and can become unmanageable during offshore installation. Because of this the generator weight should be limited, which if the wind turbine rating is increased to 10MW will be very difficult to achieve with conventional technologies. Because of this, superconducting wind turbines for offshore applications, where the airgap flux density can be increased and hence the size of the generator can be reduced, might become commercially viable in the coming decade. This initial stage of the course helped the students conceive (CDIO) the problem at hand.

Hands-On Experience

The students gained hands-on experience with finite element (FE) modelling of electrical machines, where each group had to build their own working FE model of an electrical machine. The first group constructed a small scale HTS machine prototype and therefore built an FE model of this machine, which was validated with experimental measurements of the constructed prototype. The second group built an FE model of a large scale 10MW HTS wind turbine generator. To make the FE simulations more realistic, the second group used input from the first group, who had an experimentally validated FE model of a small-scale HTS machine. The third group built an FE model of a 3.0MW PM direct drive wind turbine, which should correspond to what is publicly known about a commercially available 3.0MW direct drive PM wind turbine generator. Once the 3.0MW model had been completed a scaled up 10MW version was designed, which was used as a comparison generator or a reference that the large-scale 10MW HTS generator from the second group could be compared to. During this stage of the course the students collaboratively designed a solution for the problem at hand (CDIO), and implemented that solution in the form of building finite element models as well as constructing a small scale prototype (CDIO). Once implemented the students tested the prototype to validate the small scale FE and examined the available power in the large scale FE models (CDIO).

Applied Generic Skills

The generic skills of teamwork, negotiation, communication and presentation were exercised throughout the course and the demonstration of these skills became part of the final assessment. The groups had to work as a team on the assignments and were free to choose the path they wanted to reach their goals. Such freedom in the learning process requires that the students work as a team, and use their negotiation and communications skills to present and argue their ideas. The students also had to write a report on their contribution and give a poster presentation and a video presentation of their work. The reports and the presentations were used to assess the course. The students were therefore not only assessed on the technical content of the course but also on their applied generic skills.

The assessment was pass/not pass and all 9 students passed the course. It could be argued that the students would have been more motivated to work hard, if they knew that a mark was waiting at the end of the course. However, the experience from this course was that the students worked hard throughout the three week period and that they worked hard on the presentations. It was noticed that the students did not spend as much time on the reports, which would only be read by the teachers and hence would not become available in the public domain.

Presentation

The course was part of the Grøn Dyst (Green Match) initiative [9] at the Technical University of Denmark, where 200 students competed in presenting the best sustainable solutions to the modern society. The Grøn Dyst ended with a conference contribution, where the students had a chance to present their project and ideas. Based on these conference contributions a winner was chosen and an award was presented.

The conference contribution for the course described in this paper was split in two. A poster presentation where the students argued the potential of HTS direct drive offshore wind turbines and where all parts of their work was presented. Secondly, a video demonstration of the constructed HTS machine prototype was made, where the machine was tested and cool-down was demonstrated. The machine had to be cooled down to 77K (the boiling point of liquid nitrogen at atmospheric pressures), which caused vigorous evaporation of the nitrogen and worked very well for a video demonstration.

The conference contribution was given in a large forum, where fellow students and local companies were invited. As a novelty the Danish minister of energy and climate visited all the presentations and handed out the prizes for the best projects.

CONSTRUCTING THE HTS MACHINE PROTOTYPE

The HTS machine prototype was constructed such that the students could validate their FE model and such that they could get hands-on experience in applied superconductivity. The budget for constructing the prototype was very limited which was a challenge, because HTS machines are notoriously expensive and have therefore not yet been launched as a commercial product. As the prototype was constructed as part of the three week course, the time limitation was also very strict, resulting in a further challenge.

To simplify the construction, a standard two pole induction motor stator was used that was fixed to a customised aluminium frame, see figure 2. The rotor was custom made from soft magnetic steel and the HTS tape was wound around the centre piece of the rotor, see figure 3.

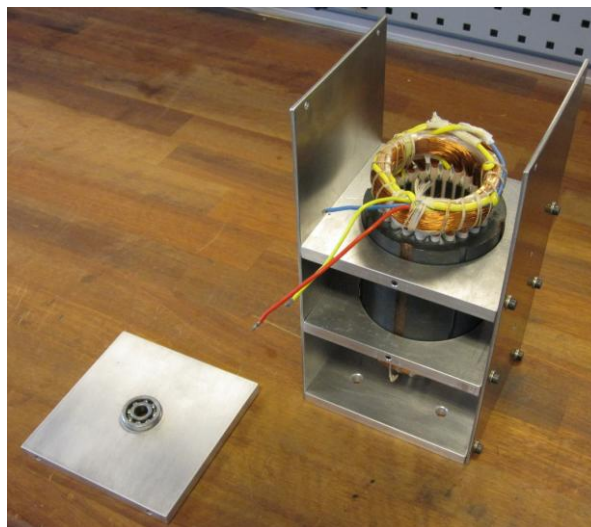


Figure 2. The two pole induction motor stator mounted in a customised aluminium frame with a brass sliding bearing at the bottom and a ball bearing at the top.

In an HTS machine, dc current is constantly supplied to the HTS tape. As the rotor, which contains the HTS tape, normally would spin, slip rings would be required which was not feasible in this low budget three week course. Therefore a static machine was constructed, where the torque and airgap flux density could be measured as a function of rotor angle. Figure 4 shows the machine setup with the handle that was used to demonstrate the torque as a function of angle.

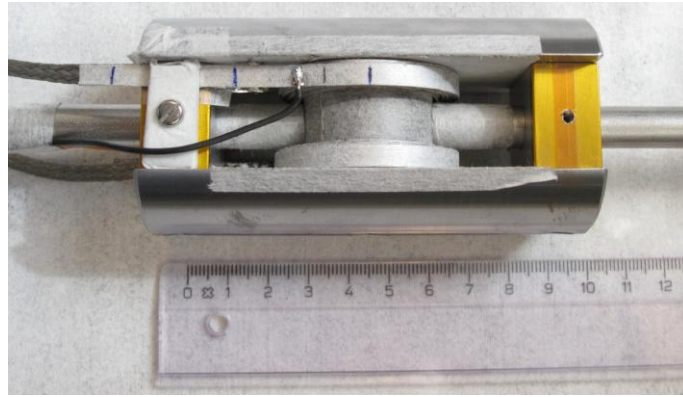


Figure 3. The two pole custom made rotor with HTS tape (4 mm wide and 0.2 mm thick) wound around the rotor centre piece and a shaft to connect the rotor to the aluminium frame and the ambience.

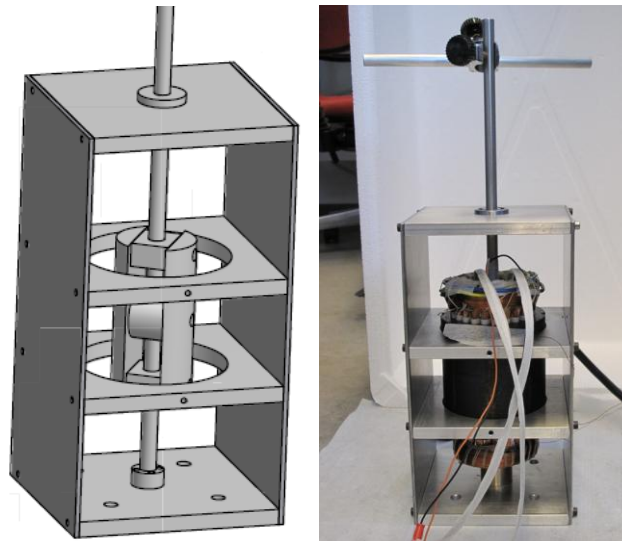


Figure 4. Simple HTS machine demonstrator, with a handle to demonstrate the torque as a function of angle. The figure on the left is a CAD drawing where the stator is excluded and the figure on the right shows the complete machine.

The superconducting machines that have been constructed and proposed in the past usually have a cold region, where the superconductors reside and a warm region at ambient temperatures for the rest of the machine. The cold region would normally be thermally insulated by a cryostat and cooled down to 30-40K by a cryocooler. Buying or constructing such components in this context would be completely unrealistic, as they would cost tens of thousands of dollars. A solution to this was to buy a flamingo box where the entire machine could be submerged into liquid nitrogen, figure 5. This machine therefore did not have two separate regions, but rather had the entire machine placed in a cold region.



Figure 5. The HTS machine prototype setup after cool-down and during testing.

TECHNICAL RESULTS

The three groups of students all built FE models of electrical machines. As mentioned earlier the first group built an FE model of the constructed small-scale HTS machine prototype; the second group built an FE model of a large scale 10MW HTS wind turbine generator; and the third group built an FE model of a 3.0MW and a 10MW PM wind turbine generator.

First Group

The first group could validate their model against experimental measurements. This model is seen in Figure 6, which shows the HTS machine prototype split in half axially due to symmetries. The model had to be three dimensional (3D) because the flux has a natural 3D path in the rotor, where the flux will concentrate in the centre of the rotor and spread out in the pole pieces of the rotor. The first group could feed their validated information to the second group, who did not have a chance to validate their simulations experimentally, although their model could be validated against analytical calculations.

As the machine could not rotate due to the lack of slip rings, it was not possible to measure the induced voltage, power or other quantities associated with rotating operation of the machine. It was however possible to measure the torque of the machine as a function of angle and the airgap flux density. The torque was measured by a simple Newton Meter attached to the handle. The airgap flux density was measured by inserting a Hall probe in the airgap. The students also estimated the critical current from the FE model of the machine and ensured that the current supplied to the HTS coil was below the critical current, which would cause the superconductor to go into a non-superconducting state.

The measured torque and the torque from the FE simulations is found in figure 7 on the left. The measured airgap flux density and the flux density from the FE simulations is found in figure 7 on the right. The equipment used by the students to measure the airgap flux density and the torque, was not state-of-the-art equipment but rather simple low-budget solutions.

The simulation results and the experimentally measured results are therefore considered a rather good match.

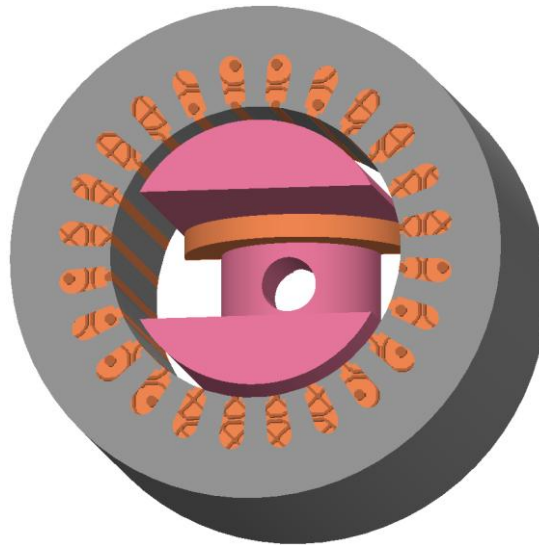


Figure 6. 3D finite element model of the HTS machine prototype. Purple: soft iron of rotor; brown: HTS tape circular winding; gray: stator core; and brown with crosses and dots: stator copper windings

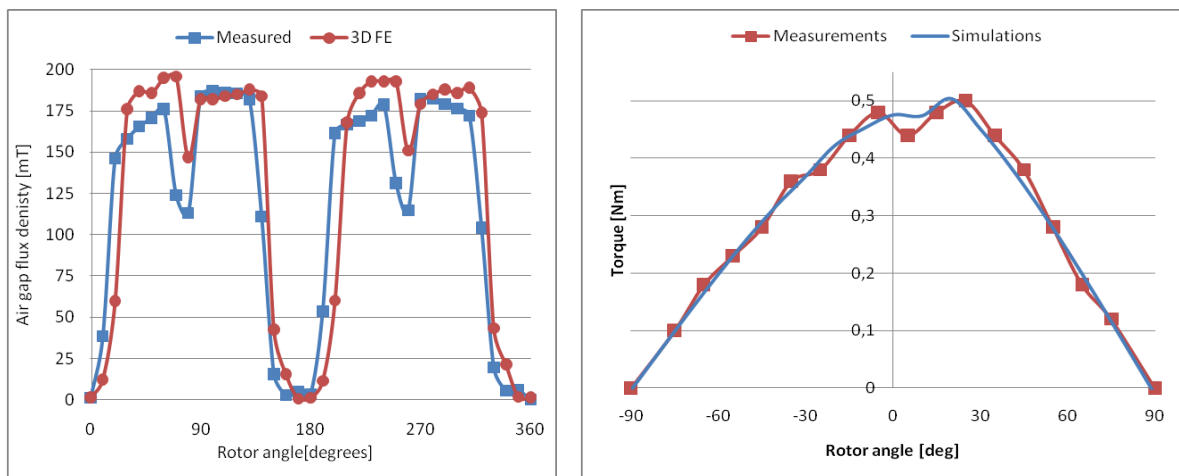


Figure 7. Experimental and simulation results for airgap flux density and torque as function of the angular displacement of the rotor with respect to the stator magnetic field at $T = 77$ K. A constant current of 50A was applied to the rotor and peak stator current of 1.0A was used in the torque experiment.

Second Group

The second group built an FE model of a large scale 10MW HTS wind turbine generator. The purpose of this model was to show that it could be technically feasible to design a 10MW HTS generator that had a manageable size for wind turbine applications. The students did not design a “ready to build” generator, which would take man-years to complete, but made a simple model that demonstrated the benefits of applying superconductors to electrical machines. To make the FE simulations more realistic, the second group could use input from the first group, who had an experimentally validated FE model of a small-scale HTS machine. The FE model from the second group is found in Figure 8 and the results for comparison with the PM generators from the third group are found in Table 1.

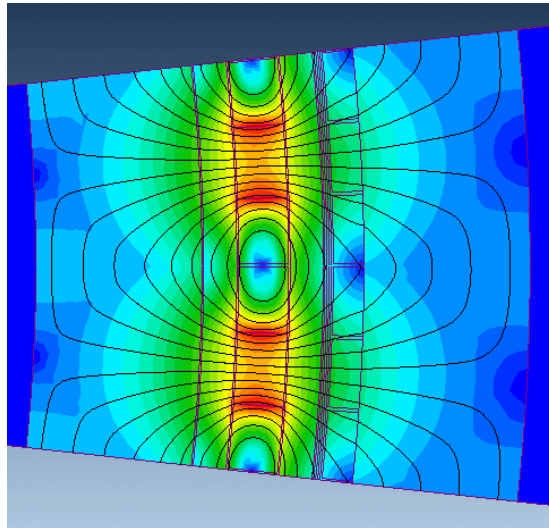


Figure 8. FE model of one pole pair of a 10MW HTS wind turbine generator set up and analysed by the second group.

Third Group

The third group built an FE model of a 3.0MW PM direct drive wind turbine, which should correspond to what is publicly known about a commercially available 3.0MW direct drive PM wind turbine generator. Once the 3.0MW model had been completed a scaled up 10MW version was designed, which was used as a comparison generator or a reference that the large-scale 10MW HTS generator from the second group could be compared to. The FE model for the 10MW PM generator from the third group is found in Figure 9 and the results for comparison are found in Table 1.

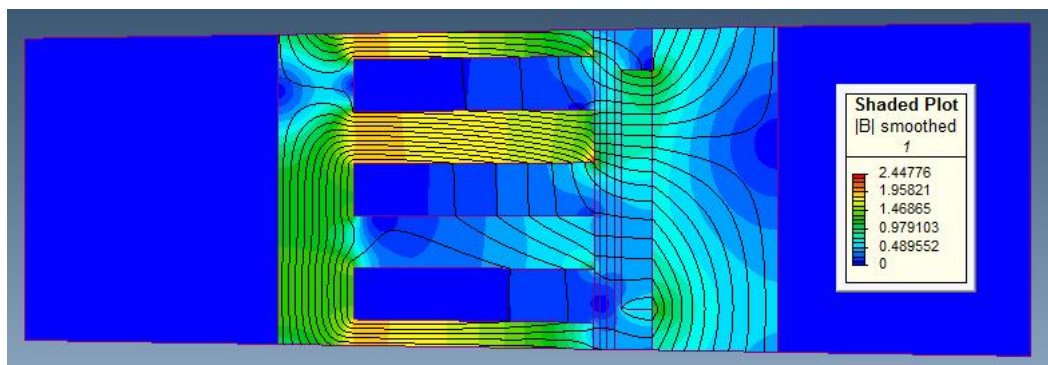


Figure 9. FE model of one pole of a 10MW PM wind turbine generator set up and analysed by the third group.

The simulation results for the HTS wind turbine generator and the PM wind turbine generators are found in table 1. Based on these simulation models the argument for HTS wind turbine generators became very clear to the students. Looking at the size of the generators it is clear that the 10MW HTS generator designed by the students in group three, has a similar size to the 3MW PM generator designed by the students in group two. Therefore it became very clear to the students how superconductors could be applied in electrical machines to construct a small machine with a high power output. In this way, the students gained hands-on experience, through which they learned how superconductors can be used in a relevant practical application.

Table 1
Comparison of the students results for the HTS and the PM wind turbine generators

	3MW PM	10MW PM	10MW HTS
Power rating	3MW	10MW	10MW
Outer radius	4.2m	8.8m	5.0m
Length of generator	1.4m	1.7m	1.2m
Volume of generator	19.4m ³	103.4m ³	23.6m ³

The authors would like to emphasise that the technical specifications of the designed PM and HTS generators found in Table 1, should not be referenced as valid research, because the designs have been made by students in a three week period and have not been validated or in any way optimised by any staff members.

STUDENT SURVEY

The quality of the course was surveyed by interviewing students after the course had been completed and after the assessment had been completed. An interview was chosen in favour of a written questionnaire as this could provoke a discussion, where other aspects could be brought forward that otherwise would be difficult to assess in a questionnaire. As the interview was conducted after the course and the assessment had been completed, the students felt safe to give their honest opinion on the course. It could still be argued that students would have difficulties expressing their honest opinion in an interview with the teacher. However, this was not noticed and would not be expected in Denmark, where a very relaxed student/teacher relationship is the norm. Denmark is also known for its flat structured hierarchy, which also was one of the reasons for choosing this quality assessment scheme rather than a written questionnaire. The survey response can be divided into three categories: positive, negative and suggestions.

Positive

The short heading *positive* covers the factors that motivated the students to work hard and take ownership of their own learning. These factors are summarised in bullet points:

- The three week course was an elective course and therefore the students would only choose it if they were interested in the topic. This gave a good foundation for motivation.
- Most of the students (8 out of 9) had taken an introductory course on electrical machine design in the previous semester and saw this course as a chance to apply the theory that they had learned.
- One of the four departments that taught the course is a research institute (Risø) based off-campus. The contributions from Risø were considered a novelty to students who would spend most of their time on-campus.
- The interdisciplinary nature of the course exposed the students to a wider field of study, than a more traditional course would.
- The course was a three week intensive course, where the students only focused on one course. This allowed the students to retain the focus on one topic for three weeks, rather than switching between courses as would be common in an academic term.

Negative

The short heading *negative* covers the factors that did not work so well during the course. Generally the feedback was positive and the students were satisfied with the course. However, there were aspects that did not work as well as they could have. These factors are summarised in bullet points:

- It was felt that communication between the three groups did not work as well as it could. The group that constructed the small scale HTS machine prototype took pictures during the construction period and shared this with the other groups. But it was felt that overall the communication between groups was lacking.
- The group backgrounds were too similar. 8 out of 9 group members were electrical engineering students, who had studied introductory electrical machine design, whereas the 9th group member was a mechanical engineering student. It was felt that the group strengths were too homogeneous and that further benefits could have been gained if the group members had more diverse backgrounds.
- In the poster presentation all of the material had to be presented on one poster, meaning that the work from three groups had to be presented on one poster. It was not felt that there was sufficient space to adequately present the students' work with only one poster.

Suggestions

The suggestions on how to improve the course in the future are summarised in bullet points:

- It was suggested that an online group would be formed, either as part of a social networking website or as part of the university website, where the individual groups could post daily updates on their progress. In this way the group communication could be improved significantly. Such a group was available but the students were not sufficiently informed and therefore did not use it.
- It was acknowledged that learning should be the student's responsibility, but it was suggested that more guidance was provided in how the groups should organise themselves. The group organisation when it came to the final presentation and which contribution that would be made by each group did not work optimally. This could have been improved if the students were better informed early on in the course, about the presentation format and the amount of work that it would require to prepare the presentations.
- The students would have preferred to receive a mark in the assessment rather than a pass / not pass. The reason for this being that the students were motivated to work hard during this course and would therefore be more likely to receive a high mark, which would contribute towards a higher final average mark.

CONCLUSION

This paper describes a multidisciplinary three week course on applied superconductivity shared by four departments. Each department contributed with their expertise and aided in creating a multidisciplinary learning environment. The course was assessed by a report and a presentation, consisting of an oral part and a video demonstration part. The purpose of the course was to teach applied superconductivity in a relevant application that the students could identify with. Applied superconductivity is naturally a multidisciplinary topic, where

physics, mathematics and several engineering disciplines are involved. It was therefore natural that such a topic was taught as an interdisciplinary course.

The quality assessment of the course was carried out by interviewing the students after the course had been completed and after their assessment had been completed. The student assessment showed that the students were generally pleased with the course and the interdisciplinarity of the course. In addition, the students felt motivated partly because the course was an elective course; an intensive three week course; an interdisciplinary course; and that there were off-campus activities. Most of the criticism from the students was based on the communication between groups and the group organisation, when it came to the final presentations. The students therefore suggested for the future, that the teachers would spend some time on facilitating improved group communication.

If such a course was given in the future, then a more standardised form of project management and documentation could be implemented, such that it would be easier to offer the course to larger groups of students. This course was very special in that some of the students built an electrical machine prototype. Such prototypes would be relatively expensive if several were to be built, but the learning exercise of modelling a machine and validating the results experimentally is very valuable and might be considered more valuable than the construction of the machine. One way of opening up for larger number of groups, would be by allowing the students to carry out experiments on the already constructed machine and use that data to validate their finite element models of the machine.

Based on what has been reported, the authors feel that the course went well and that the course objectives were met through the different course activities.

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