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Christensen, Hans Peter; Molin, Jesper; Schelling, Adriaan

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Umbrella Courses at the BEng programme in Civil Engineering at the Technical University of Denmark

H.P. Christensen,
J. Molin,
A.H. Schelling

DTU Center for Bachelor of Engineering Studies
Building, Environmental and Civil Engineering
Technical University of Denmark

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ABSTRACT

Based on solid principles for learning, a curriculum for our BEng programme in Civil Engineering has been built around large interdisciplinary so-called umbrella courses. Within a digital framework, the courses – in a novel way – combine motivating project work on authentic cases with embedded theory modules to generalise the learning, giving the students coherent, sustainable and applicable competences including important generic competences. The students find the umbrella courses very challenging, so a firm structure with a high level of information and rigorous planning has been necessary. Developing the umbrella concept has been a long and challenging, yet qualifying process for the teaching teams made up of engaged professors from several departments, and the rewards are now beginning to show. The students feel they get good learning, which is seen in the high grades, and older students, who first experienced the umbrella course, now see the value of the interdisciplinary approach and praise the courses for laying the foundation for a good education.

1 INTRODUCTION

Based on the CDIO standards (CDIO, 2004), a new curriculum for the Bachelor of Engineering programme in Civil Engineering was implemented from autumn 2014. The hallmark of the new curriculum is the large umbrella course, which collects all the necessary topics to complete a project as in an umbrella organisation. The umbrella course is the core of the first and second semesters. The inspiration for the umbrella course came from a merge of two existing programmes, the civil engineering design process, basic principles for learning, and the CDIO teaching concept. Designing buildings and infrastructures is getting more and more computerized, so it is important to give the students the coherent viewpoint necessary to build multidimensional all-embracing computer models.

CDIO was developed to get practice back into engineering education; Conceive-Design-Implement-Operate emulates the way engineers are working, and this is fully

1 Corresponding author:
A.H. Schelling, Associate professor
adsc@dtu.dk
implemented in the umbrella course, as it fits with the phases in the way buildings and infrastructures are designed and constructed.

One of the requirements of a CDIO programme is that it should include two Design-Build projects. This is implemented in surplus, since the four first semesters are all built around Design-Build projects. CDIO also specifies a syllabus with an emphasis on generic competences – i.e. collaboration, communication etc., which directly are in focus with the learning objectives in the umbrella courses.

The aim of the umbrella-based teaching is primarily that the students will achieve a deeper, more useful and coherent understanding of the topics in a civil engineering education. This should give a good starting point for the second year, where the student goes deeper into the theory.

Secondly, the umbrella courses aim at keeping a high retention rate. Not all students have been top performers in high school, so many have difficulties starting a demanding higher education like engineering. And not all students are clear about what civil engineering is, so the motivation may not be high from day one. Therefore, dropout rates should be kept low during the first year. However, at the same time, it is also important quickly to stop students, who clearly have chosen the wrong education. The umbrella course structure should, through respectively group work and the focus on individual learning, live up to both these somewhat contradicting goals. The independent work should also help to transform the student from school pupil to university student.

This paper aims to

- Describe the teaching method and structure of the two umbrella courses.
- Present a preliminary evaluation of the two courses, in terms of student dropout rates, grades, and student satisfaction.

First, we outline the existing theoretical background for the design of the courses. Secondly, we describe the two courses: their teaching method and structure. Next, we outline the evaluation methodology. Finally, we present the evaluation results and discuss the findings and limitations of the evaluation.

2 EXISTING LEARNING THEORETICAL BACKGROUND

Learning is an active emotional process that fuelled by sensory and cognitive input takes place in the growth layer between the known and the unknown (Christensen, 2008). The umbrella courses are based on empirically well-documented principles for learning – e.g. described in How People Learn (Bransford et al., 2005). Two of the main conclusions are that learning is an emotional psychological process and that learning requires activity – we can only learn, if we need to and are interested and actively engaged: Need-based active learning (Kurki-Suonio & Hakola, 2007). It is all about motivation. Deep learning requires internal motivation; external motivation like passing an exam doesn’t give sustainable learning (Bruner, 1977). Students must be put in a situation, where they must learn in order to carry out an activity they want to do. And designing buildings and infrastructures must be interesting and motivating for civil engineering students.

Another learning theoretical point is that to develop competences within an area, you need to have a solid factual knowledge base understood in a relevant conceptual
The aim of the umbrella-based teaching is primarily that the students will achieve in focus with the learning objectives in the umbrella courses. On generic competences built around Design-Build projects. CDIO also specifies a syllabus with an emphasis on Build projects. This is implemented in surplus, since the four first semesters are all one of the requirements of a CDIO programme is that it should include two Design- and infrastructures are designed and constructed.

This paper aims to understand needs for successful students. This should give a good starting point for the second year, where the students have obtained the necessary basic understanding of all topics in the course for their continuing studies. A student cannot participate in the final exam unless she/he has passed all the learning checks. Most checks are one-hour online multiple-choice tests with questions that check the student’s understanding; not the ability to remember knowledge or do calculations.

3 TEACHING METHOD AND STRUCTURE

The main part of semester 1 and 2 of the BEng programme in Civil Engineering consists of two umbrella courses. An umbrella course is 15 weeks long and takes up 2/3 of a semester. It is built around a project with an authentic case with embedded theory modules including relevant math and physics providing the necessary knowledge and skills to complete the project. Most modules are given at the beginning of the course, and then more and more time is allocated to the project. In the final three weeks there is only project work. In addition to the theory modules, the umbrella courses include hands-on activities like construction, field surveys, and lab work.

The students work in fixed groups throughout the entire course. All groups have a process facilitator to help them with the difficult teamwork. As a counterweight to the group work, the students must participate in individual learning checks throughout the course. The purpose of these is primarily to give the student feedback on her/his learning, which is essential to learning (Argyris, 1992), but also to ensure that all students have obtained the necessary basic understanding of all topics in the course for their continuing studies. A student cannot participate in the final exam unless she/he has passed all the learning checks. Most checks are one-hour online multiple-choice tests with questions that check the student’s understanding; not the ability to remember knowledge or do calculations.

The students are graded on the final project documentation including a process document and an oral presentation with individual questions in order to give individual grades. The students are expected to be able to explain every aspect of the case and the corresponding theories.

3.1 Semester 1: Building Construction

The case is designing a one-family house – see Figure 1 for an example of a student project. Digital construction is the framework for the course, which has the following theory modules:

framework (Bransford et al., 2005). Learning is contextual – that is why it is so difficult to apply math learned in a pure math environment. The context bound case-related learning must be generalised. This is the reason for the unique way the umbrella courses are designed with embedded theory modules. And the delivery of these modules must be closely aligned with the progress of the project, so the students have them, when they need them; the difficult just-in-time planning and coordination.

We learn on basis of what we already know: Our horizon of understanding. The big picture does not make sense, if we don’t know any details, but we are not motivated to learn the details, if we cannot use them and see them in the big perspective. This is the hermeneutic circle (Gadamer, 1960). So, neither a top-down nor a bottom-up approach is useful. We need to have all the information from the start which is, of course, not possible. Therefore, we must start with a few details and a simplified overview, and then add more and more details and create a better and better total view: The rationale behind spiral learning (Bruner, 1977). This is the theoretical reason for the phase structuring of the umbrella course with clear learning objectives for each phase. There is also a practical engineering reason for this, as the civil engineering design process is standardised in phases from idea generation to operation and removal. A spiral process where more and more information is added to the model.
The course aims to introduce basic building knowledge through the design of a single-family house, with the involvement of the industry's forms of communication and forms of collaboration. The building design deals with building technology, the building's load-bearing construction, energy calculations and the building's installations. The students must acquire knowledge of the building design's prerequisites through insight into building regulations and local plan, as well as applicable norms, standards and building practices.

The aim of the course is that the students acquire tools for constructively entering into and contributing to the group's collaboration, and that the students are introduced to the industry's digital communication forms with special emphasis on BIM, Building Information Modelling.

The course and the course assignments will be divided into the following phases:
- Appraisal
- Project proposal
- Regulatory project and tender design

During the course the students do presentations of the progress with the case after each phase, but this is not part of the grading.

Figure 2 shows the learning outcomes for the Building Construction course. In addition to the technical disciplinary knowledge, the CDIO Syllabus specifies the learning outcomes as personal and interpersonal skills, as well as skills in product, process, and system building skills. The figure shows which of the individual learning out-
comes will contribute to the students’ learning in each of these four sections.

3.2 Semester 1: Training in Process and Collaboration

Together with the teaching in engineering subjects, it is an important learning objective to acquire skills in team working and collaboration through the first year. The idea is to support the students’ transition from school pupils to students of engineering.

From the beginning, each group is required to write a Collaboration Contract, and we train the groups to carry out conducted group discussions where they reflect on the working process. As a result of the reflections, each individual student will state what he or she will do to contribute to targeted improvements of the team’s working process.

During the first semester, there are regularly scheduled sessions where the focus is on the process, not the technical content of their work. At the end of the semester,

A student who has met the objectives of the course will be able to:

- Apply digital forms of communication with emphasis on (BIM) Building Information Modelling.
- Explain the phases of construction including construction management, financial estimates, scheduling.
- Design a small residential building with a focus on the whole, building construction and building materials.
- Dimension a simple structural design, including conducting a preliminary static analysis.
- Perform basic design of the building envelope and the building’s heating and ventilation systems.
- Calculate and simulate the expected energy use of the building.
- Document the suggested solutions and communicate and argue the solution in writing and orally.
- Explain the learning group process cooperation.

Figure 2 shows the learning outcomes for the Building Construction course. In addition to the technical disciplinary knowledge, the CDIO Syllabus specifies the learning outcomes as personal and interpersonal skills, as well as skills in product, process, and system building skills. The figure shows which of the individual learning outcomes will contribute to the students’ learning in each of these four sections.

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 enterprise and societal context

Figure 2: Learning outcomes for Building Construction. Colour code according to the four sections of the CDIO Syllabus.

each group prepares a Process Document. Furthermore, two times during the first semester, a personal conversation of 15 minutes length between each individual student and a professor is scheduled. The first round of conversations takes place in the middle of the term, and the second at the end, closely to the final examination. In this second conversation, the Process Document is commented.

These individual conversations are held in an atmosphere of respect and personal interest, and the professors conducting these conversations are not a part of the teaching team of the first semester – thus eliminating the potential fear of telling something that might influence negatively on the student’s examination.

3.3 Semester 2: Civil Infrastructure Engineering

The 20 ECTS Umbrella Course for the second semester aims to enable the students
to plan, design and renovate municipal infrastructure facilities, based on municipal planning, traffic conditions, and supply conditions. The course is project organized and includes six theory modules as well as a continuous project.

The requirements for our cities change over time; this also applies to roads and paths, drainage and water supply. They must be renovated so that they meet today's and tomorrow's requirements for road safety, accessibility and climate protection.

The learning outcomes – displayed in Figure 3 - describe the knowledge, skills and competences the students will acquire.

The various subject areas are gathered in a continuous project, dealing with an existing, older industrial area in suburban greater Copenhagen. In the Municipal Urban Area Development Plan, the area has been designated as an urban conversion area. The transformation has begun in the area's north-eastern corner. Here, a high-rise residential development has been erected on an old industrial site. This gives rise to new requirements for the traffic system - including the need to identify a need for a better school route that must overcome the barrier that the railway constitutes.

A student who has met the objectives of the course will be able to:

- Describe and analyse a project organization for an infrastructure project.
- Identify and locate traffic problems.
- Develop and assess the implications of solutions to traffic problems.
- Design roads in urban areas.
- Plan and design distinct systems for water supply.
- Plan and design distinct facilities for drainage, including renovation of drainage systems.
- Acquire knowledge and implement hydraulics for pipes and canals systems.
- Analyse geological conditions, perform basic geotechnical calculations and plan and interpret typical geotechnical studies.
- Design minor civil structures such as retaining walls.
- Develop schedule and economic estimate for the design and construction.
- Communicate and argue for the assignment in writing and orally, with focus on digital tools such as GIS, Geographic Information Systems.
- Explain team cooperation and development and reflect on the use of personal and interpersonal skills.

Figure 3: Learning outcomes for Civil Infrastructure Engineering. Colour code according to the four sections of the CDIO Syllabus.

Along the area's eastern border an upcoming light rail line will further boost the development. There are many large commercial buildings and a large part of the area is paved. The southern part of the area includes allotment gardens.

The six theory modules are:

- Geotechnics and Structures (4 ECTS)
- Climate, Water and Environmental Engineering (5 ECTS)
- Roads and traffic (5 ECTS)
• Planning and Process Management (3 ECTS)
• Geoinformatics (1 ECTS)
• Hydraulics (2 ECTS)

In the spring semester of 2018, the 107 students were organized in 18 groups of generally 6 students. Before the term begins, the students are invited to form pairs of two or three students, and to indicate with which other students they would like to form a group. These pairs were then combined to groups of 6 students by the course supervisor. The students respond very positively to this invitation: 90 per cent of the students have indicated preferred teammates.

The teaching team included 11 professors from 3 different Technical University institutes and from the industry, as well as seven teaching assistants – older students, helping the groups understand the matters and getting started.

Each group is assigned a process supervisor. The process supervisor must guide the group in relation to
• manage their time and resource plans so that milestones are not moved
• follow-up on the collaboration contract
• facilitate collaboration problems

Six of the professors are also process supervisors. The meetings are scheduled every two weeks in the beginning of the course, and later there is a meeting once a week.

Figure 4: Example of a project drawing from the Infrastructure Engineering course: A WSUD (Water Sensitive Urban Design) solution for the Herlev Business District.

All faculty can provide professional guidance. If students need specialist guidance
outside the scheduled teaching sessions, they send an email with a request for a meeting, including an agenda. At the end of the course, each group prepares a Process Document. It is included in the final assessment.

3.4 Semester 2: Considering Assessment

The goal is that the assessment is aligned with the teaching method and the learning outcomes. The course is evaluated by an oral group examination based on the project report and the process document. During the course 6 tests are held, and to be able to take the examination 5 out of 6 tests must be accepted. Everyone is assessed individually. In the spring semester of 2018, the project examination included 107 students, 20 groups, 2 days, 3 rooms, 3 external examiners, and 7 professors.

Hand In. The groups handed in their project electronic on the university’s teaching platform one week before the examination. The groups are requested to deliver their material in a predefined file structure, according to the Danish Building Information’s Standard.

Marking. The individual subject professors review, comment and evaluate the material of all groups as regards their own subject area. This is done on commentary sheets. The process documentation is evaluated and commented by the group’s process supervisor. This process can take maximum four days.

Preparation. The examiners (process supervisors) receive all comments and all printed drawings from the subject professors and provide an overall impression of the individual group’s performance. This process can take maximum one day.

Examination. The process supervisors carry out the oral examination, together with one colleague who has another professional profile. The groups hand over a printed agenda for the presentation to the examiners. The students are instructed to leave enough time for questions and discussions (one third of the total time)

Examination Time

- Group presentation Geotechnics and Structures 18 minutes
- Group presentation Climate, Water and Environment 18 minutes
- Group presentation Roads and Traffic 18 minutes
- Group presentation Planning and Process Management 18 minutes
- Group presentation Process 10 minutes
- Voting 10 minutes
- Buffer/pause 10 minutes
- Total 102 minutes
- Rounded up to (1 hour and 45 minutes) 105 minutes

4 EVALUATION METHODOLOGY

This preliminary evaluation study is based on the two umbrella courses on semester 1 and 2 of the BEng programme in Civil Engineering. The earlier versions of the courses, which ran from 2014/15 to 2016/17, were included.

The data are all routine information, collected from the grade statistics and from the standard university course evaluation system. In this system, the students are invited to answer 9 questions about the course, and in addition, there are several questions about each professor. The students may also write text-comments.

Three of the 9 questions were selected for this study, as they were – in this connection – the most relevant ones. The other questions deal with the students’ active par-
ticipation, the teaching material, their own performance and the course description’s prerequisites. The three selected questions are shown in section 5.2.

As pointed out earlier, a deeper understanding of the topics in a civil engineering education was expected, and a low dropout rate.

5 DOCUMENTATION AND DISCUSSION

5.1 Dropout Rates and Grades

Both umbrella courses have, as expected and intended, a very low dropout rate, with approximately 90 % passing.

The average grades for the courses are, as shown in Figure 5 and 6, around the average grade of 7 – for the first semester course, grades tend to be lowest in the spring semesters which include more students who have been away from school for some years. However, after the study plan adjustment spring 2017 there is a significant increase in the average grade for the first semester course reaching 9.3 in spring 2018.

It should be noted that it is the same core of professors and external examiners, who have run the exam all the years, so the grade increase must be assumed to be a real expression of a higher learning outcome. For the second semester course, a similar increase is not seen.

![Average grades Building Construction](image)

**Figure 5: Average grade for the first semester umbrella course on a scale from 0 to 12. The results from autumn 14 to autumn 16 are for the original course, the results from spring 17 to spring 18 are for the revised course.**

![Average grades Civil Infrastructure Engineering](image)

**Figure 6: Average grade for the second semester umbrella course on a scale from 0 to 12. The results from spring 15 to spring 17 are for the original course, the results from autumn 17 to autumn 18 are for the revised course.**

5.2 Standard Course Evaluation

Figure 7 and 8 show the answers to the selected questions from the standard university student evaluation since the introduction of the umbrella courses autumn 2014 and spring 2015 respectively. The three selected questions are:

- Q 1.1: I think I am learning a lot in this course
- Q 1.5: I think the teacher/s create a good continuity between the different teaching activities
- Q 1.8: In general, I think this is a good course
Figure 7 (left) and 8 (right): Average answers for 3 questions on the standard university student course evaluation for the two umbrella courses on a Likert scale from 0 completely disagree to 5 completely agree (data for autumn 16 are not available for the second semester course).

For the first semester course, the results are slowly getting better until the curriculum adjustment spring 2017, where there were problems with the introduction of the learning checks. After that, the results have increased. For the second semester course, the results are slightly better, and more stable.

5.3 Further studies

This preliminary study has already caused implementation of several changes in the teaching concept but leaves a few interesting questions which deserve further investigation:

1. What is the value of the learning checks, and how to improve them?
2. What are the reasons and solutions to the students’ feeling of confusion?
3. How can the complex topics be made more understandable to new students?

5.4 Dissemination

The umbrella concept has been presented at a CDIO conference (Winther, 2016), and recently, the umbrella course has received the Technical University’s teaching Award 2018.

5.5 Conclusions

The innovation described here is not just about a promising new way to teach – it is about changing the philosophy behind traditional curriculum design: From The Technical University norm with independent 5 ECTS courses to a fully aligned curriculum with large interdisciplinary courses based on proved learning principles and in accordance with the CDIO concept and industrial standards. The core umbrella courses have a novel architecture designed to create motivation and assure deep applicable learning. To implement this has been a challenge to both students and professors, so this has been a long developing process with necessary adjustments along the way.

If you give the students demanding challenges, they will find it hard and at first be frustrated, but the learning will be deep and sustainable, and the benefit to the students will be great in the long run. But students don’t see the long run, so you must make courses motivating and relevant with transparent methods and objectives. That’s why and how we made the umbrella courses. When talking to older students and graduates, they express that the umbrella courses they were exposed to at the beginning of their study now make a lot of sense to them. They can see that the in-
terdisciplinary approach gives them a good basis for further learning and strong job competences.

This is, in the end, what the umbrella course curriculum is all about.

REFERENCES


[4] CDIO Standards: [http://cdio.org/content/cdio-standard-21](http://cdio.org/content/cdio-standard-21)


