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Conceive — Design — Implement — Operate (CDIO): A Case Study in Undergraduate Engineering (Wind Energy Course) at DTU

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Abstract

As a result of a mismatch between the skills of the newly trained engineers and the needs of industry, a new approach called Conceive — Design — Implement — Operate (CDIO) has been designed for producing the next generation of engineers [1]. CDIO is a structured approach to how and when the students acquire technical science / engineering and general / personal competencies, which takes place simultaneously through lectures and projects.

At the Technical University of Denmark (DTU), we have, since 2008, joined a network a large number of international universities and implemented the framework to develop a new undergraduate CDIO-based program[1]. The efforts are made in order to transform from an authoritarian teacher-based learning to a student-centered counterpart thereby achieving an active, life-time learning experience for the students.

The course “Design-Build 2: Wind Energy Harvesting” aims at getting students engaged in a problem-based engineering project to design and build wind turbine blades in order to achieve the most efficient conversion rate of the wind into electrical energy. We have been running the course two times, having a diverse student background ranging from life science to mathematics backgrounds as well as diverse nationalities. This article presents our observations in implementation of the CDIO technique in student activation and satisfaction. Challenges in facing “lost students” and implementing the technique correctly are being discussed and advantages in student activation are analysed. In addition to acquiring strong academic knowledge, it is shown that through various steps of the 3-weeks course period, students develop both personal, social and professional skills that are important for their upcoming professional career.

CDIO methodology

The vision of the CDIO approach is “to educate students who can understand how to conceive, design, implement and operate complex value-added engineering systems in a modern team-based engineering environment” or described in a more simple way “Engineers who can engineer”.

The CDIO goals are 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 and finally to understand the importance and strategic impact of research and technological development on society [3].

The CDIO approach to engineering education was implemented in 2008 at DTU and is being practiced in a number of undergraduate courses ever since [2]. This article present our implementation of the methodology in the renewable energy course, 10240 Design-Build 2: Wind Energy Harvesting. The course will be presented in the following section.

The General Engineering BSc Study Program

The General Engineering program, as the only undergraduate program offered in English at DTU, is a technical-scientific undergraduate study program. Through a program consisting of 180 ECTS units, students start with taking a number of mandatory courses such as mathematics, physics and chemistry followed by the design/build projects to gain the spirit of engineering. Students will then finish by specializing in one of the four focus areas: ‘Living Systems’, ‘Cyber Systems’, ‘Cyber Materials’, or ‘Future Energy’ and get ready for further education through various MSc programs [1]. Figure 1 shows the program structure and details of the courses to be taken in order to receive a BSc in General Engineering at DTU.

01006: Advanced Engineering Mathematics 1 10 ECTS Schedule: E5A+E5B+E3B	01006: Advanced Engineering Mathematics 1 10 ECTS + Cases from various engineering topics Schedule: F5A+F5B+F3B	01034: Advanced Engineering Mathematics 2 5 ECTS Schedule: E1A 47203: Design-Build 3 – Heat Recovery 5 ECTS 3 weeks January	33270: Design-Build 4 –Self-Contained Systems 5 ECTS 3 weeks June
10018: Physics 1 Cases for all tracks 5 ECTS Schedule: E3A	10018: Physics 1 Cases for all tracks 5 ECTS Schedule: F3A	42610: Philosophy of Science in Engineering 5 ECTS Schedule: E3B	
26030: Fundamental Chemistry Cases for all tracks 5 ECTS Schedule: E2A	02402: Introduction to Statistics 5 ECTS Schedule: F4A (for some specialisations this course is in 4th term)		
02631: Introduction to programming and data processing Python mandatory 5 ECTS Schedule: E1B	10240: Design-Build 2 - Wind Energy Harvesting 5 ECTS 3 weeks June		
27016: Design-Build 1 – Devices for measuring cell growth 5 ECTS 3 weeks January	Choose 1 of: 12701: Living Systems Eng. Schedule: F2A *************** 41680: Intr. Cyber Materials Schedule: F1A 5 ECTS	Choose 1 of: 02135: Intr. Cyber Systems Schedule: E4A *************** 47202: Intr. Future Energy Schedule: E3A 5 ECTS	

Figure 1: Programme structure and detailed content of the UG general engineering course at DTU. Each column represents a semester (from

[1] It should be noted here that the terms “Program” and “Course” in this article refer to “Course” and “Module”, respectively, in an English higher education system.

left to right). Various colours indicate which of the 4 focus areas are covered by respective courses. Red, orange and purple boxes indicate a total of 45 ECTS credits (each) of "Basic Natural Science", "Projects and Professional Skills Courses", and "Technological Specialisations", respectively. "Electives", shown in blue in DTU website, and BSc project are not shown here and are offered in the last two semesters [1].

Course construction Design-Build 2: Wind Energy Harvesting

The proposed course is taught in the first semester of the Bachelor of Engineering education at the Technical University of Denmark. The 5 ECTS course follows the Design-Build 1 course of the first semester and further introduce the students to the CDIO concepts. The overall aim of the course is to develop the students' competences within the various aspects of wind energy. The problem to be solved in this course is efficient conversion of wind kinetic energy into electrical energy and during the course, students are expected to design and build a model of wind turbine blade that matches their choice of generator. Given a wind turbine setup and electrical generator, the part to be optimized is the form of the wind blades. As can be seen, the course is a substantially cross-disciplinary one with skills in aerodynamics, electrical engineering and instrumentation needed to be successfully implemented.

Course Outline

Based on some introductory lectures, the students will design and manufacture their own wind turbine with a 3D printer and measure the resulting energy conversion efficiency as a function of wind speed. To this end, interdisciplinary student teams will be formed with special consideration for the required skills/competencies needed for the problem.
Given the time constraints of the 3-weeks course, special emphasis will be put on the development of an efficient project plan with appropriate time management. These plans will be presented and peer-reviewed during the course.
Besides for their overall efficiency, the blades can (if time permits) also be evaluated for their durability under heavy wind load. Another optional subproject could be the deconvolution of the individual part's efficiencies, e.g. the influence of the electrical generator. Data collection will be performed in available setups in Nanoteket lab, where it is possible for interested students to dive further into computer based data acquisition based on LabView.

Learning Objectives (LO)

Learning objectives are defined based on Bloom's taxonomy [4] and cover a range of achievable and clear aims in various levels including the likes of "explain the concepts", "devise and execute a project plan", "apply design principles", "explain and adapt the data acquisition setup", "measure the energy conversion efficiency of the produced blade". Analyse, discuss evaluate and present are also used to describe the LOs.

Course design

In the current implementation, the course runs in a 3-week period, all week days.

Team formation: Students are assigned to groups of 4 students by the mentors in such a way that each group represents a student background.

Time for activities: Students are then given freedom to choose the time slots for their activities (figure 2) during the course based on a Doodle service (Design/Implement).

Technical briefing: A number of lectures on the introductory material are given in the mornings and students are asked to do research in order to understand their assignment and to solve it in a practical sense (Conceive).

Mentorship: a number of PhD students, acting as facilitators (teaching assistants) are interacting with students on a daily basis (Operate).

Evaluation and Feedback

During the course, various feedback questions and sessions and corresponding mentor's reflection were planned and implemented to gauge student's satisfaction and activation. Examples of some of the feedback sessions will be shown hereafter.

Assessment

Finally, the project plan, blade design and measured data will be written in a poster and presented at the exam session (figures 3 and 4). This poster will be the basis of the final, summative assessment (fail/pass). In the final assessment session each group member should be able to defend the entire poster.

Figure 2: Participation of student groups in the practical work (Implement/Operate). Test rig used by each group during wind tunnel experiments.

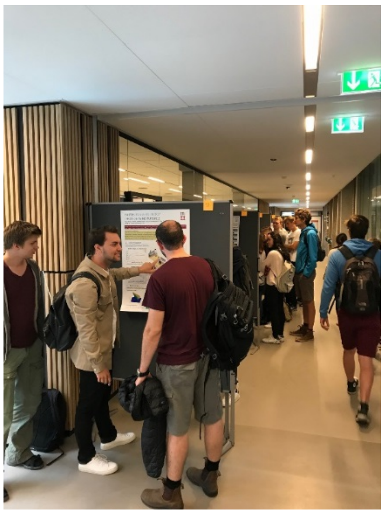

Figure 3: Group poster presentations during the exam.

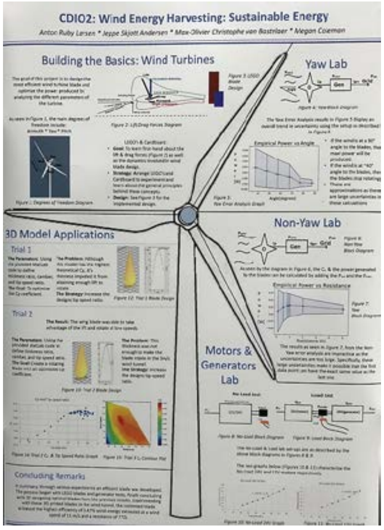

Figure 4: A sample poster presented by a group during the exam.

To receive a very quick feedback from majority of students, for instance, small sheets of paper with boxes marked 1/5 (worst) up to 5/5 (best) were distributed among students asking them to mark their evaluation of the lecture and optionally write a line or two at the back side of the paper.

Table 1 shows some of the positive and negative comments during a lecture in Aerodynamics.

Table 1: students' feedback during a selected lecture

Positive	**Negative**
Good lecture, very HOT room!	Very poor air – so hard to follow!
Use of Kahoot, Learning Objectives, Summary + instructiveness of the lecture	More videos would have been nicer
	Very intense lecture
Knowledgeable lecturer – very clear	Simple material – should have been more in depth

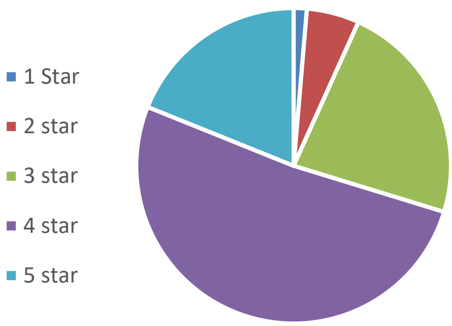

Figure 5: Student satisfaction chart. 70% satisfaction is obtained by counting 4* and 5* votes.

Towards the end of the lecture, a course evaluation was performed. The toolbox Menti (www.menti.com) was used and students were asked to name whatever they have enjoyed the most during the class. Figure 6 shows how such learning technologies can be used in the classroom for getting students opinion in a short matter of time and at the same time, activating the class from silence. As can be seen from the figure, a clear tendency to the wind tunnel activity was found. It could also be found that students appreciate the freedom they are given in forming their groups and managing their tasks. A similar vote was made and we asked students to describe the course in one word. In that case, there was no preferred answer although the word "unorganised" was relatively boldly represented. We believe while the nature of a CDIO course could have led students, especially those less familiar with the concept, to choose this answer, there are certain ways the course can indeed be run in a more organised way – still within the CDIO allowed limits.

Figure 6: Quick student feedback as to the most exciting part of the course

Results from various evaluations show that while majority of students appreciate the teaching methodology and learning activities and effectively use their time management and teamwork skills, they see a problem in terms of overall organisation of the course. Another issue as raised by some students is the fact that different students have different views on the scientific level of the course, mainly due to their own background. During the course, reflection from the teacher was

> Thank you for all thoughtful comments last time!
>
> Results were generally positive (70% 4* and 5*) and comments were quite instructive!
>
> Lecture slides uploaded before the lecture: noted .. Though sometimes not possible!
>
> Some of you complained about the room temperature and air quality. For that, we can only hope the weather gets colder - do we really want that though :)
>
> Some suggested that the lectures could be more in depth using mathematical formulas and so on, while others believed the lecture was already way too complicated. This usually happens when students are from diverse backgrounds like you guys. One way to overcome this situation is for you to "ask" any questions you have in mind.
>
> Many of you were happy with having a video clip and some suggested we need more online activities like the Kahoot test. I'm listening to you! This lecture has some more video clips and quizes :)

Figure 7: Informal reflection from the teacher after student evaluations.

given regularly to the students. An example of a reflection is shown in figure 7.

Students' evaluation and feedback are useful tools to adjust both curriculum and the teaching methodology. In the next section, an attempt has been made to pinpoint the flaws and strengths of the above course.

Conclusions and suggestions for improvements

The CDIO adaptation using laboratory and research environment has enhanced enhance student-centred-learning and given students satisfaction of "freely" choosing their short term goals within the course. In addition, the CDIO initiative has helped to demonstrate the interdisciplinary nature of the wind energy harvesting course, since students have faced various disciplines involved in the course (aerodynamics, electrical engineering and experimental techniques epscifically). There are, however, still practical challenges to be faced such as students' perception of the method and subsequently, there is a demand from them to be more "organized". In this article, we have shown that mutual, and multiple-time feedback can help overcome some of the challenges.

A number of considerations have been planned for a more successful execution of the course during the next academic year:

1. Currently, the aerodynamic design of blades are being conducted using a lengthy Matlab script. Explanation of the code itself has caused a considerable amount of time as well as confusion among some students, while not being the core focus of the course. The use of more simplified tools is therefore being considered. A survey has been performed and the GUI based software, QBlade®, is chosen as a proper candidate for further consideration. QBlade (figure 8) is an Open source toolbox that innovatively combines capabilities of a number of software packages used for design of wind turbines. It uses Blade Element Momentum Method (BEM), Double Multiple Streamtube (DMS) and nonlinear Lifting Line Theory (LLT) for the design and simulation of Vertical- and Horizontal Axis Wind Turbines. The software includes tools to setup and simulate the internal blade structure and perform an aeroelastic analysis of a wind turbine rotor in turbulent inflow conditions. The program features an easy-to-use graphical user interface – contrary to its previously-available sub-components such as FAST and other commercial design tools.

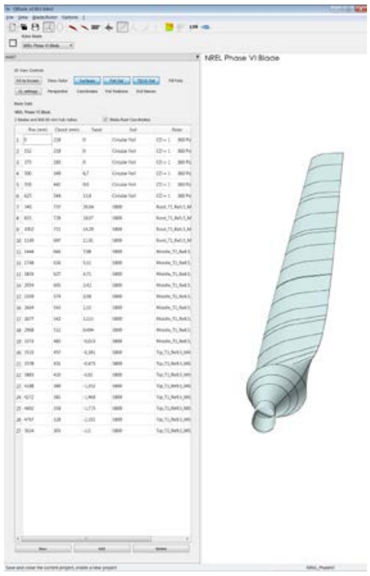

Figure 8: The open source software QBlade.

2. Knowing that students recognise the wind tunnel activity to be the most valuable element of the course and in order to reduce the waiting times for the students to try their constructed blades in the wind tunnel, it was decided to investigate possibility of constructing a number of low cost wind tunnels using laboratory fans and cardboard tunnel cross sections and generally investigate on development of labs and workspaces that support the increasing number of students.
3. Better organisation and planning of the course in terms of a clear time schedules for particular lecture in advance of the start of the class is another factor that needs to be addressed. This will be pursued actively during the next year.

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