CDIO PROJECTS IN CIVIL ENGINEERING STUDY PROGRAM AT DTU

Anette Krogsbøll
Claus Simonsen
Jørgen Erik Christensen
Tina Beier Larsen
Per Goltermann
Holger Koss
Jørgen Sand

Technical University of Denmark

ABSTRACT

In 2008 all Bachelor of engineering study programs at the Technical University of Denmark (DTU) have been adopted to the "Conceive – Design – Implement – Operate" approach. As part of the necessary changes it was decided that all seven study programs should have a cross disciplinary project or a design build project on each of the first four semesters. In this paper the four projects in the civil engineering study program are described along with a brief description of the entire study program. The aim is to provide additional information and documentation to accompany an exposition where students present their projects. Learning outcomes, training and assessment of personal, professional and social engineering skills are described from a project point of view. Progression of engineering skills is discussed from a study program perspective. The interrelation between the various elements to the final learning outcome is discussed with respect to the concept of the study program as it is today. Barriers for reaching the ultimate goal, that all students become "engineers who can engineer" at a high technical level, are identified and discussed. It is concluded that the study program has all the potential to prepare students to cope with the challenges in engineering practice, but it also shows that the degree of success depends on the amount of barriers along the way.

KEYWORDS

Design-build projects, civil engineering, student presentations, study program, progression.

INTRODUCTION

When the CDIO approach to engineering education at DTU was implemented in 2008 the design of the curriculum was based on a long tradition for educating civil engineers, [1], [2]. Sparsø et al [1] described the process of implementing the CDIO approach at DTU in general, and also discussed the barriers and advantages of introducing a new concept in a conventional teaching environment.

The vision of the CDIO approach is "*to educate students who understand how to Conceive – Design – Implement – Operate complex value-added engineering systems in a modern team-based engineering environment*", [3], or more simple: "*Engineers who can engineer*", [3,], [4]. Crawley et al, [3], defined a set of standards which defines an education based on the CDIO approach. These standards are approved and considered fundamental by the CDIO community.

A plan for the implementation process at DTU was developed, [1], with focus on those standards in the CDIO approach concerning the Program Philosophy (Standard 1), Curriculum development (Standard 2, 3 and 4) and Design-Implement- experiences and workspaces (Standard 5 and 6), [3].

Vigild et al [2] described the design build activities in several educations at DTU as they were implemented in 2008, and how the projects were fitted into the general course structures. In the DTU model [4] two design build projects and two other interdisciplinary projects are included in the program within the first four semesters, [2]. The new curriculum within civil engineering is organized mostly as an integrated curriculum, according to definitions by Edstöm et al in [3]. Remains of the original disciplinary curriculum from before 2008 are though still visible – especially in 1st and 2nd semester. After the overall structure of the curriculum was established integrated learning activities and aligned assessment were in focus next, and the importance of that, as described among others by [5], [6], [3], [7] and [8], were recognized.

The 1st and 4th semester design build projects were described and evaluated by Christensen et al [9] and by Krogsbøll et al [10]. In both cases focus was on learning outcomes, active learning and integrated learning activities related to the design build experiences. In both cases the studies indicated that students did improve on engineering skills, but also that improvements are possible [9], [10]. As a consequence, focus in these years is on raising the level of coordination between the different activities within each semester, and to make the connections and progression more clear to the students.

One important factor for the success of implementing a new approach in a well established study program is the challenge of force of habits of students as well as of teachers, [3], [5], [11]. The enthusiasm among the teachers and coordinators is high in the beginning of a process of redesigning the curricula and implementing the new approach, but seems to fade with time. Christiansen et al [11] described these effects and indicated ways to sustain momentum in the process of implementing CDIO. A handbook for CDIO implementation at DTU, [4], has been developed and gives guidelines for faculty and study program coordinators in order to keep focus on the CDIO approach. Christiansen et al [11] also pointed out that motivation and acknowledgement of faculty and involvement of the faculty in coordination between separate parts of the study programs would help to increase enthusiasm. As part of the process to increase knowledge and understanding of the CDIO approach among students and faculty in general and in order to stress the importance of a learning oriented culture, [11], we would like to contribute to an exhibition with design build projects and interdisciplinary projects within civil engineering.

In the following the civil engineering study program is described briefly, the four interdisciplinary projects, of which two are design build projects, are described and finally the progression within engineering skills and the coordination between different elements in the curriculum are discussed from a program point of view.

CIVIL ENGINEERING STUDY PROGRAM

The first 2 years consist of a combination of fundamental courses covering mathematics, physics, mechanics and core engineering courses relevant within civil engineering. From the technical point of view there have been only minor changes in “what to teach” as compared to the curriculum from before implementing the CDIO approach. As far as personal, interpersonal, professional and engineering skills are concerned there have been major changes. The skills are now defined through learning outcomes. To some extent the assessment methods have been adjusted to be aligned with the learning outcomes, and the teaching methods have clearly been modified to involve more active and integrated learning, as defined in the CDIO standards 7-8 about teaching and learning methods, [3].

The basic structure of courses at DTU is with two semesters each year. Each semester consists of a 13 weeks period, followed by a 2 weeks period of exams and then a 3 weeks period with a fulltime course activity. Each course equivalent is 5 ECTS points, and during the 13 weeks period typically 5 courses run simultaneously, so in total the student is supposed to get 30 ECTS points during a semester.

In Figure 1 the study program for civil engineering students is outlined, and the four cross disciplinary projects of which two are design build projects, are highlighted along with related activities. In this context the relations refer to the technical knowledge and reasoning (CDIO Syllabus category 1, [3]).

In the following subsections each of the CDIO projects are described in more detail with comments on teaching and assessment methods and learning outcomes within engineering skills from CDIO Syllabus category 2-4 as well.

<table>
<tr><th></th><th colspan="6">13 weeks semester</th><th>3 weeks</th></tr>
<tr><th></th><th>5 ECTS</th><th>5 ECTS</th><th>5 ECTS</th><th>5 ECTS</th><th colspan="2">5 ECTS</th><th>5 ECTS</th></tr>
<tr><td>1</td><td>Mathematics 1</td><td>Mechanics 1</td><td>Physics</td><td>Design within building energy</td><td colspan="2">Design build 1. Small house</td><td>AutoCAD</td></tr>
<tr><td>2</td><td>Mathematics 2</td><td>Mechanics 2</td><td>Programming</td><td colspan="3">Hydraulics and environmental engineering</td><td>GIS, GPS, setting out for buildings</td></tr>
<tr><td>3</td><td>Probability and statistics</td><td>Mechanics 3</td><td>Material science</td><td>Concrete structures</td><td>Beam experi ments</td><td>Digital models BIM</td><td>Material Science Experiments</td></tr>
<tr><td>4</td><td>Steel and wood structures</td><td>Soil Mechanics</td><td>Installation systems</td><td colspan="3">Design of buildings, planning and management of buildings. Digital model of the building</td><td>Concrete, steel and wood struc.</td></tr>
<tr><td>5</td><td colspan="7">Practice in a company fo 5 months</td></tr>
<tr><td>6</td><td colspan="7">Elective course</td></tr>
<tr><td>7</td><td colspan="2">Elective courses</td><td colspan="5">Final B. Eng. project</td></tr>
</table>

Gray: Mandatory courses
Light gray: Course that hosts a design build project
Thick borders: Interdisciplinary projects and design build projects across courses.

Figure 1. Study program for civil engineering students.

Semester 1 – CDIO Design build project

The first Design-build project is part of an introductory course, which serves to introduce the students to basic civil engineering, and to make them aware of the variety and complexity of engineering and to the cooperation that is needed to achieve results - and to document and present them. The introductory course is in accordance with standard 4, [3].

The design-build assignment is to design and build a small model of a family house in scale 1:20. The house should be able to hold a temperature of 20˚C, so heat loss is a topic. The heat loss is measured in a natural environment outside in early spring or late fall. The course is paired with a course in basic design methods in building energy in the same semester. The work has to be done in teams of 4 students in groups defined by the teachers.

The overall teaching strategy aims at introducing the students to both engineering skills as well as to the very nature of a house. At the very first day of studies students are presented with the task to describe in writing their own home. They are free to emphasize technical or more general terms. The written description is then exchanged with a fellow student. The student now has to translate the description into a drawing of that home. The students meet afterwards to discuss their written description and their drawings. This task is to enable the students to activate their vocabulary about buildings and to give them a peek of the complexity between thoughts and ideas of a building and the means of communicating about them.

Most of the students are uneasy with the concept of creating their own parameters for a building solution. By introducing points of focus, we push creative thinking and enabling the students to discuss various aspects of the building and how they are related. Of course the main objective is to minimise the heat loss of their buildings, but this opens up for different ways of accomplishing that objective. Some of the focus points do not even support the main objective directly. Many groups put down daylight as point of focus and many teams simply argues that good daylight is a quality of a building. As students work other topics arise, like building energy, indoor climate, orientation to the sun and the act of human living.

Drafting is another key factor of this course. The ability to communicate and create your design in drawings is essential. It forces the ability to think in real solutions and how to build them. Drafting is a way to test your design and how you plan to build it. Design - test and redesign. We make it clear that drafting has to be an integrated part of the building process, and encourage updating the drawings throughout the entire building period.

The teams present and document the work in the design phase in an oral presentation and a written report. These reports are then exchanged and reviewed by other teams. This helps the students in a dual way. They receive comments and advices from teams with another set of parameters and they are themselves reviewers, who can test and challenge a report on the basis of their own set of parameters. By reviewing and advising others you also become more aware of strengthens and weaknesses your own work.

As the building process progresses most teams apply new features or they change their design. It could be changes in building materials or adding more insulation for instance. These changes have to be documented, and the whole set up of drawings and calculations has to be updated. This process is very valuable as it states the concept of cause and effect, which is vital for the engineering thinking.

The model houses are placed outside at the campus for a period of 2-3 weeks. A small heating unit is placed inside the houses and produces heat at a predefined effect. The teams measure the effect and the temperature inside and outside the houses every 3 minutes in the operating period. After a week the teams make a change to the house and observe the difference. That could be blinding windows or repositioning the house relative to the sun. The large body of data then has to be processed and analysed - and compared to the calculations of the design phase. In this comparison they have to take the entire process into consideration and select the most plausible arguments to support their conclusions.

To sum up basics of this Design Build course; creating an idea of a house, based on a collective assessment, extent it by defining its parameters, test it in drawings, calculations and by comparison to others, build it by the means of design and redesign and compare your real measurements data to your parameters and calculations and conclude this into a coherent solution that you can call a house.

The students train many of the engineering competences from the syllabus category 2 and 3, [3], which we would like the students to learn before they call themselves engineers.

Semester 2 – CDIO Interdisciplinary project

The 2nd semester project is a cross disciplinary project including two separate courses within programming and hydraulics and environmental engineering. The students work in both courses on projects concerning drainage and flood problems as a result of climate changes.

In the hydraulics and environmental engineering course, student gain basic knowledge to hydraulics, and learn to use that for designing heat- and indoor climate systems and public water supply and urban drainage systems. In this course the assessment is a combination of exams and reports, and both individual and teamwork assessment is part of it. The requirements for the quality of the technical reports are increased as compared to 1st semester, since progression is expected and accounted for.

In the programming course students learn basic programming elements in the first two thirds of the semester, and at the end, they do a final project in which they have to include knowledge form the course in hydraulics and environmental engineering. They have to write a program, that models the distribution of rain water on a surface subject to extreme rain fall and various drainage conditions. The students are provided with data on topography of the surface area and rain fall data, and they investigate by use of their own programme how drains affect the water level, and they analyse the consequence of intensity and duration of rain falls. The students have to develop, test and document their program. The documentation is not a report, though. They are provided with a test program, by which they are able to control whether their own program does the right calculations, and have the right output as specified in the assignment.

So far the interaction between the courses in the 2nd semester has been limited to common topics, and to the fact that in order to understand the theories and methods used in the programming course the students have to utilize their mathematical and mechanical understanding, which is also part of the learning outcomes in 2nd semester courses.

Semester 3 – CDIO Interdisciplinary project

The theme of learning activities and courses in 3rd semester is “The Beam“. This is what we define as the 3rd semester interdisciplinary CDIO-project. They do beam experiments in the late part of the semester, and before that they learned various relevant topics in other courses:

- Probability and Statistics (how to treat data statistically, probability distributions);
- Mechanics 3 (how to estimate capacities in general);
- Concrete Structures (how to design and analyze a concrete beam);
- Material Science (how to design a concrete mix).

These courses make use of a combination of lectures and supervised exercises. The contents in brackets indicate the main parts of the courses used in the beam experiments and are taught prior to their use in the CDIO-project.

The CDIO-project covers the design, casting, curing, testing, reporting and evaluation of concrete beams and is completed before the examination period for the other courses.

The progression from a technical point of view is therefore quite clear: 1) Students learn basic knowledge in lectures and exercises, followed by 2) design and production of the concrete beams and additional test specimens, 3) testing of beams and specimens and 4) reporting and analysis of the results and observations, 5) examination in the courses and 6) lab testing course in the 3 week period.

The CDIO-project improves the student's general understanding of the topics in the courses and provides a good motivation for the following course with laboratory exercises in the 3 week period. It has been observed that lab activities tend to improve the student's ability to handle unexpected situations (which they often create themselves) and that the analysis and reporting provoke serious reflections to the results and their correlation to theory.

The CDIO project course "Beam experiments"

The course "Beam Experiments" is given twice a year: in spring the course subject is a reinforced concrete beam and in fall a lattice steel beam. In both cases design theory, structural linear and non-linear behaviour under static loading, prediction and testing of the overall carrying capacity and the determination of material properties are integrative parts of the course. The detailed description refers to the subject of a reinforced concrete beam. The course is structured into following main elements:

Theoretical design of the beam: the students have to apply design methods from previous courses and from lectures given in parallel to the experimental course. This is in particular the course on "Concrete Structures".

Manufacturing of the beam: in groups of four to five people the students have to prepare the reinforcement in the formwork, make the concrete of a required strength quality, cast the beam, make tests on the fresh concrete (slump-test and air content through application of pressure method – Figure 2) and cast specimens (cylinders and cubes) for testing material properties of hardened concrete. The combination of reinforcement and concrete quality varies amongst the groups.

Figure 2. From left to right: concrete blending, beam casting,
slump-test and air content measurement. Photos: Holger Koss.

Test of beam, test specimens and reinforcement steel. After 28 days of hardening, the beam is equally loaded at two points. Increasing the load stepwise the linear elastic behaviour is registered for both phases, i.e. with and without cracks. Hereafter the beam is loaded until either the tensile strength of the reinforcement or the compressive strength of the concrete is exceeded (Figure 3, left). At the same time six cylinder specimens and three cubes are tested to determine the compressive strength of the concrete. One cylinder is equipped with strain gauges to estimate the material elasticity (Figure 3, centre). Finally, the tensile strength of reinforcement steel is tested. Based on the acquired data the elasticity and yield strength shall be determined (Figure 3, right).

Figure 4. From left to right: beam testing, concrete compression strength test, data acquisition, steel tensile strength test. Photos: Holger Koss.

Analysis & Documentation: The students are requested to analyse the data and observations from the experimental investigation and document the results in a technical report. The results from the tests shall be compared to the prediction from theoretical analysis.

Apart from the practical experience of how to manufacture and test structural concrete elements and the comparison to theoretical design methods the students should gain a deeper understanding of following aspects:

Almost all values and parameter used for structural design in civil engineering are based on experimental investigations. Here, the course makes cross-reference to the parallel courses on “Material Science” and “Material Science Experiments”. Special emphasis is laid on the determination of the characteristic value of the concrete compression strength as a 5%-fractile. With this aspect the fundamental philosophy of the Eurocodes regarding semi-probabilistic design is addressed and interlinks with the content of the parallel course on “Probability and Statistics”.

Finally, the course strives to convey basic rules required for scientific work and experimental investigation: systematic preparation, controlled testing, proper analysis and comprehensive but focused reporting and documentation. As compared to the requirements to reporting in 2^{nd} semester the students learn to go one step further.

Semester 4 – CDIO Design build project

In 4^{th} semester students do their second Design-build-project. Three courses are linked together, see figure 1:

- Design of buildings, planning and management of buildings. Digital model of the building – 10 ECTS
- Technical Building Services – 5 ECTS
- Soil mechanics – 5 ECTS

The students work in teams of six, and form the same groups in all three courses. They design structures, installations, foundations and various elements of the house in details and from a holistic point of view. They verify that the design is technically appropriate and that it satisfies the requirements of law. The project is based on a real design by architects with drawings given to the students. They build a digital model of the building and use it for verification purposes and planning of the construction phase. So here is a connection the third semester (Figure 1), where students learn the basic application of digital building models in a separate course. In many other Design-build courses the students will build and operate their project, however since it is impossible to build the houses in full scale the design build activity is focused on the digital model, Figure 4. After designing they should plan the construction phases, make time schedules and budgets as if the project was a real project for an engineering company. The Design-build activity is related to the digital model of the buildings, by which they are able to control whether their design is coherent and afterwards they can compare their model to the model made by other groups. They are examined partly by the report, but also have to present their design in an oral examination and be able to argue for choices made during the design phase.

Figure 4. Design-build Course in the 4th semester, spring 2011. Photos: J.E. Christensen.

The students learn interpersonal skills, personal and professional skills, such as multidisciplinary teamwork, communication, planning and leadership. There is no direct teaching in these skills, since the course is based on integrated learning activities, and the students are assessed based on the these skills as well as the technical ones. The work load in this course is high, and if the students do not cooperate and plan the process they will suffer from lack of time. Students tend to be more satisfied with this course when it is all over than when they are in the middle of the process. We know that this is basically because they focus on the technical part of the learning outcomes, more than on the engineering skills. That has been confirmed from inquiries made earlier, [10], and is similar to evaluations of the design build course in 1st semester.

COORDINATION AND PROGRESSION IN CURRICULUM

All courses at DTU are defined by a general description in an open access course catalogue, [12]. Technical content of the course is defined with lists of prerequisites. As part of the definition learning outcomes for a student who completes the course as intended are listed. The levels of understanding are considered to be based on Blooms taxonomy, [13], and rated in the levels: knowledge, comprehension, application, analysis, synthesis and evaluation. In the DTU model, [4], the levels of understanding are slightly modified, [1], so comprehension and application could be learned in any order.

The coordination of progression in terms of Blooms taxonomy, between semesters and in the entire study plan is coordinated by the study plan coordinator with the help of faculty members and students in a coordination board.

Technical knowledge, workload and assessment methods

As can be seen now, coordination and coherence between technical topics within each semester are considered to a certain level and the coherence increase with complexity level – so at 3rd and 4th semester almost the entire group of courses are related. This provides students the experience that the various technical topics they learn are supplementary to each other and are used to solve engineering problems that cross the traditional technical borders as appear from the division into courses.

The teachers on each semester meet regularly and coordinate activities in order to make sure that the workload for the students are spread all over the semester. It is not possible to avoid increased level towards the end of the semester, but coordination certainly helps to minimize the problem. Different types of assessment are applied to different courses, partly in order to assess different types of learning outcomes, but also in order to avoid too many exams in the same semester.

The standard study plan as illustrated in Figure 1 is based on progression within the technical knowledge. It is very clear when for instance the courses in mathematics or in mechanics are considered. Also within the other technical areas progression is built-in. Consequently the students should preferably follow the courses in the order as indicated in the study plan. We made use of that when progression within other engineering skills were planned.

Personal, interpersonal and professional skills

Progression within engineering skills as personal, interpersonal and professional skills is considered and listed as part of the learning outcomes in most courses. As an example, the students are introduced to technical reports and presentation techniques and the requirements in an engineering context in the introductory course at first semester. They get feedback, and are asked to give other students feed back as well. These processes are included in the assessment. In the second semester the requirements and complexity level increase in the reports. During third and fourth semester they are trained in other types of written communication, since they learn about laboratory reports, scientific papers, technical documentation reports and digital models of buildings.

They have mandatory teamwork in several courses. In some courses, process reports or other types of activities are included in the assessment. The complexity level is increased during the four semesters – not only technically, but also size of the groups and the requirements to coordination and project planning and presentation. And most of all the level according to Blooms taxonomy is also increased.

The ability to make judgements, to evaluate results and pick out the important parts and so forth are trained and included in the assessments – and we expect the students to learn doing this better and better, and they are assessed according to that.

Finalising the study

After 4 semesters with mandatory courses the students are in a company for 5 months. During that period they learn many technical things, but most important they learn a lot from the CDIO syllabus category 4 as well, [3]. The period of practice is evaluated based on three types of reports each focusing on different aspects of the practice – and referring to different learning outcomes. The final year serves as the student's possibility to specialize technically, and the coordination is absent. The Bachelor thesis should fulfil certain requirements that meet the overall learning outcomes from the study program.

CONCLUSIONS

The study program for bachelor of engineering students within civil engineering is described. CDIO projects are described, and examples of assessment and teaching methods are given. Also successes and ideas for improvements are identified

The coordination between different elements in the study plan and progression during the study are both described and discussed.

This general overview of the study program is suitable to serve as a guide to an exhibition of students' projects, since reasoning behind activities are outlined here.

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Biographical Information

Anette Krogsbøll is Associated Professor at Department of Civil Engineering, and Programme Coordinator of the Study Programme for Bachelor of Engineering in civil engineering at DTU.

Jørgen Erik Christensen is Associate Professor at Department of Civil Engineering, and member of the CDIO implementation board at the department. From 1997 to 2001 he studied gestalt therapy with specialisation in communication at the Norwegian Institute for Gestalt. In 2009 he studied: “Pedagogical and Didactic Theory about University Education and Teaching” at the Danish Pedagogical University, Denmark.

Tina Beier Larsen is External lecturer at Department of Civil Engineering, and also structural engineer in the private company of consulting engineers, Lemming & Eriksson.

Per Goltermann is professor at Department of Civil Engineering, chairman of the departments Study Board and Program Coordinator for Bachelor of Science in Civil Engineering at DTU. He has 20 years of experience as a consulting engineer prior to his position at DTU and is responsible for the courses “Basic Concrete Structures” and “Engineering Work” (introductory course for freshman students).

Associate Professor Holger Koss studied Civil Engineering at the University of Bochum (Germany) and defended in 2000 his PhD thesis in the field of Building Aerodynamics and Structural Dynamics. After working eight years in consultancy industry in civil and maritime hydro and aerodynamics he started his positions at DTU Civil Engineering, Department of Structural Engineering, in 2008. Due his background in experimental testing he was put in charge of course 11702 “beam experiments” in 2010.

Claus Simonsen is architect and external lecturer at Department of Civil Engineering. He is teacher at the introductory CDIO course, and has significant experience from industry.

Jørgen Sand is external lecturer at the Department of Mathematical Modelling. He is teacher in programming courses, and holds significant experience from industry.

Corresponding Author

Associate Professor Anette Krogsbøll
Department of Civil Engineering
Technical University of Denmark
Brovej, Building 118,
DK-2800 Kongens Lyngby, Denmark
Phone (+45) 4525 5088
email: akr@byg.dtu.dk