CDIO IN CHEMICAL ENGINEERING EDUCATION

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Abstract
This presentation reports on the experience of adapting the CDIO Standards and Syllabus to a context of chemical engineering education, namely the B.Eng. program for Chemistry and Biotechnology at the Technical University of Denmark (DTU). The CDIO was adapted recently as a decision by management. This untypical approach calls for an implementation which largely is and continues to be a task of informing and educating faculty on the CDIO. As an important first step we particularly focus on a benchmarking process of the existing program in order to create an overview of course elements and curricular activities. This will identify where CDIO elements are already present, and where there is room for improvement of the bachelor program.

Keywords: chemical engineering, curriculum change, enhancement of faculty CDIO skills, curriculum benchmarking

Introduction

In this presentation we will report on how the CDIO standards are suitably *adapted* and *implemented* in chemical engineering education. More precisely we will discuss data from the experience of changing the curriculum of the B.Eng. chemical engineering education at the Technical University of Denmark (DTU). A management decision recently dictated that the program should adapt to the CDIO Standards.

Applying CDIO as the educational context for chemical engineering is relatively unexplored as compared to its use in mechanical engineering and related areas. There are qualitative and quantitative differences in the professional and personal working attitudes and attributes of the chemical and mechanical engineer. But there are also differences in cultural and societal context of the standing of the two types of engineers. The interesting question we are focusing on in this study is what changes and modifications are deemed necessary to establish CDIO as the learning context in a chemical engineering program?

CDIO

The reality of general engineering problems and the real-life working frame for engineering practice can be described by four words: Conceive – Design – Implement – Operate. Not all chemical engineers are necessarily occupied doing all of these four aspects of this system lifecycle in their job; some will spend their whole career operating e.g. production scale facilities to manufacture bulk chemicals, others will only design chemical processes and never actually manufacture any products. Some engineers will work in consulting constantly approaching new problems and others will do commissioning setting up new production plants, but never run them over a long time. The CDIO initiative takes the real life context of engineering, which is represented by the four letters CDIO, and makes it the governing context for engineering education, so that teaching and learning activities relate to CDIO engineering practice. The CDIO Initiative has adopted 12 standards, which describe a CDIO program. [1] Seven standards are considered essential as they distinguish the CDIO initiative from other engineering programs:

- Standard 1: CDIO as Context
- Standard 2: CDIO Syllabus Outcomes
- Standard 3: Integrated Curriculum
- Standard 5: Design-Build Experiences
- Standard 7: Integrated Learning Experiences
- Standard 9: Enhancement of Faculty CDIO Skills
- Standard 11: CDIO Skills Assessment

A CDIO program is characterized by a *progression* in student learning towards a final competence profile. This means that *learning outcomes* are specified for the individual courses and these are coordinated and tuned over the different semesters of the program. The final competence profile is specified in the context of the *CDIO Syllabus*, which is a categorization of the final competences into four sections: technical disciplinary knowledge, personal leaning outcomes, interpersonal learning outcomes, and product and system building skills. A distinguishing feature of a CDIO program is that the curriculum *integrates* the training of these skills from the different sections of the syllabus by combing learning activities at course level. Another distinguishing feature of a CDIO program is an explicit plan for the whole program, which maps out how the learning outcomes for individual courses and study activities contribute to the final competence profile. This plan is called the course-competence matrix, and is a central tool in handling and ensuring that the program indeed covers the *progression* in learning skills and the *integration* of different competences.

In the following we will describe our education program and discuss it in relation to the CDIO initiative. As a first approach we are attempting a benchmarking of the existing program in order to verify already existing CDIO elements in the program, and identify white spots where modification of the program are needed in order to obtain CDIO status.

B.Eng. in Chemistry and Biotechnology at the Technical University of Denmark

The curriculum displayed in Table 1 was adopted for the B.Eng. program in Chemistry and Biotechnology at the Technical University of Denmark in the autumn of 2005. The curriculum was developed in order to better integrate the teaching of the individual courses in chemistry, biotechnology and technical (physical) chemistry, which at the time had somewhat lost its synergietic benefits. The courses are typically lecture (lect.) courses or laboratory (lab.) courses as indicated in Table 1.

Table 1. Curriculum for B.Eng. in Chemistry and Biotechnology. The ECTS credit points are indicated for each course. Courses are labeled either lecture courses (lect.) or laboratory courses (lab.), and the project leading course in each semester is underlined.

Semester						
1st	2nd	3rd	4th	5th	6th	7th
General Chemistry (5 p. lect.)	Organic Chemistry (7.5 p. lect.)	Biological Chemistry (7.5 p. lect.)	Statistics (7.5 p. lect.)	Industrial internship (30 p.)	Elective (5 p.)	Elective (5 p.)
Inorganic Qualitative Analysis (2.5 p. lab.)	Analytical Chemistry in Inorganic and Physical Chemistry (2.5 p. lab.)	Chemical Engineering Thermody-namics (5 p. lect.)	Materials Science (7.5 p. lect. & lab.)		Elective (5 p.) Chemical Reaction Engineering (5 p.lect.)	Elective (5 p.)
Physics (5 p. lect.)	Physical Chemistry (5 p. lect.)	Organic Synthesis (5 p. lab.)	Biotechnology and process design (15 p. lect. & lab.)		Process Control (5 p. lect.)	Thesis project (20 p.)
Calculus and Linear algebra (10 p. lect.)	Inorganic Chemistry (5 p. lect.)	Unit Operations of Chemical Engineering and Biotechnology (12.5 p. lect. & lab.).			Process and product design (10 p. lect. & lab.)	
Chemical and Biochemical Process Engineering (7.5 p. lect. & lab.)	Mathematical models for chemical and biochemical systems (10 p. lect. & lab.)					

As part of the curriculum installed in 2005 each semester is given its own theme, and typically parts of a bigger lecture course will be devoted to some kind of cross-course project work activity under the headlines of the semester theme. The project work will typically include activities which take place in neighboring courses on that semester, and the bigger lecture course is a kind of project host. The themes for the semesters are shown in Table 2. The motivation for the interdisciplinary themes is to create a coherent education with a holistic approach. The interdisciplinary themes also necessitates, encourages and supports teacher collaboration on developing appropriate problems for the project work. For the first four semesters such a project work is mandatory for all students. The course which hosts the project work on the semester is indicated in Table 1 as being underlined. The project starts up at the beginning of the semester and runs and evolves in parallel with other lecture or lab classes during the semester. Each semester is 13 weeks, and lecture courses are followed by examinations. After the examination period there is a three week period devoted to full time activities on just one aspect or subject. Typically this period is fully devoted to the project work which normally will be evaluated in a written report and an oral presentation.

Table 2. Interdisciplinary themes over the semesters.

Semester	Interdisciplinary theme
1st	Chemical and biotechnological production
2nd	Chemical and biochemical systems
3rd	Chemical and biochemical processing
4th	Biotechnology and process design
5th	Industrial internship
6th	Process and product design
7th	Thesis work

The program has a set competence profile specifying 13 academic competences and 11 generic competences. This competence profile is not constructed according to the classification of the CDIO Syllabus, but the competences do map onto all four categories for the CDIO Syllabus. Recently, all the courses of the program also adopted a specification of 8-12 learning objectives for each course. These learning outcomes are initially installed because of a change of the grading system in Denmark, and not because of the attempt to apply to CDIO protocol, but they will later be adapted to the CDIO framework.

Benchmarking Methodology

In order to monitor the CDIO status of the B.Eng. program in Chemistry and Biotechnology a benchmarking process is installed. The education program has not adapted the CDIO Syllabus at the present, but by using the program's own competence profile, it is possible to introduce a curriculum-competence matrix. Because the existing competence profile does map onto the CDIO Syllabus, an evaluation is made possible with respect to the four sections of the CDIO Syllabus. We perform the benchmarking process in order to validate the existing competence profile and to explore whether all areas of the CDIO Syllabus are covered. In our bench marking we suggest to use a modified version of Bloom's taxonomy, where the usual level 2 (understand) and level 3 (apply) are forked out to the same taxonomy level. The introduce-teach-use ranking system as suggested by CDIO can be integrated in our benchmarking. We also suggest a color mapping scheme for the results of our modified Bloom benchmarking, which offers a clear visual opportunity to interpret the competence matrix data, i.e. the progression of (expected or measured) competences across courses in the educational program from semester to semester. As higher levels on the taxonomy are achieved, the corresponding colors will change similar to the altitude colors of an atlas, where the colors go from dark blue over shades of green to brown and finally red. We expect that this color scheme will make it easy to see progression at-a-glance for the different competences. The color scheme for the modified version of Blooms taxonomy is shown in Table 3. A rating of "0" for a given competence and a given course means that it (as expected or measured) does not contribute to the competence. "1" indicates the level of basic knowledge, "2a" understanding and "2b" (Bloom level 3) the ability to apply knowledge (for instance in computations). Studies of science and engineering education at DTU and elsewhere have shown that there is no linear progression from conceptual understanding of models etc. to the ability to "apply" this knowledge as measured e.g. in computational exercises. Skills in "application" have to be integrated with conceptual knowledge at the higher levels, i.e. "4" indicating analytical and/or synthetic reasoning and "5" (e.g. evaluation of alternative models).

Table 3. The proposed color scheme for illustrating progression of competences in the modified version of Bloom's taxonomy (see text)

0	1	2a	2b	4	5

The bench marking process is still in progress, and we cannot here show the final results. However, as an example we show the results form the first semester, where four courses contribute to nine out of 11 academic skills. To exemplify "a6" here refers to "the ability to plan and carry through laboratory experiments" (mapping to CDIO Syllabus section 1: Technical Knowledge and Reasoning) and "a8" refers to "The ability to cooperate with other professional groups in production engineering (mapping to CDIO Syllabus section 3: Interpersonal Skills).

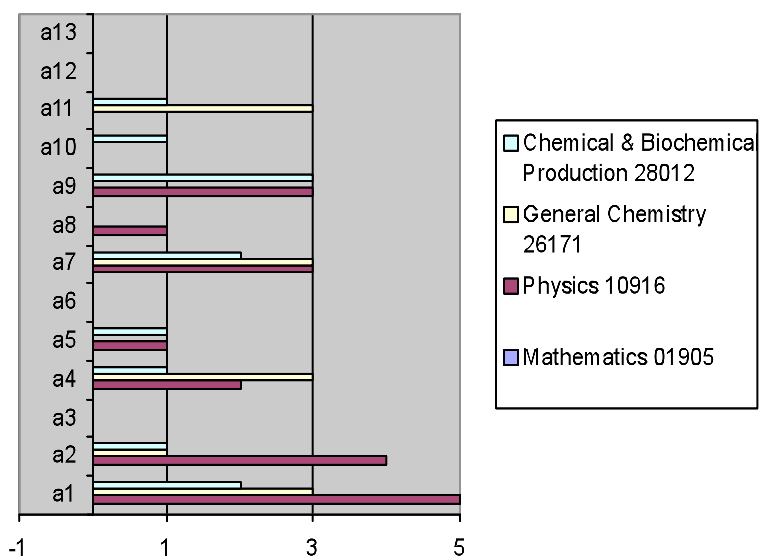

Figure 1. The result of benchmarking the 1st semester against the 13 academic competences (a1 – a13) which are defined for the B.Eng. program in Chemical and Biochemical Engineering at DTU. The learning outcomes from each course are ranked according to a modified Bloom's taxonomy (see text).

Results and Analysis

The benchmarking process

The primary aim of the benchmarking is to expose the status of the program and its present CDIO-structure and -elements. The existing educational program may already meet many CDIO Standards, and the benchmarking will give an objective judgment on this issue. Furthermore, the benchmarking can guide us as to which processes are needed to make future changes to the program and enhance CDIO implementation. Obviously the benchmarking can be repeated in a few years, and so give feed back information, useful in evaluation of the education. Unfortunately the benchmarking is still in progress and final results will not be ready until the time of the conference in June.

An instrumental part of *implementing* the CDIO concept and creating awareness (and enthusiasm) amongst colleagues was to manage the benchmarking process via interviews with the individual teachers of the program courses. This interview round also proves highly beneficial in order to enhance comprehension and mutual understanding of the CDIO elements in teaching and learning. However, the process is time consuming and calls on the resources of a committed faculty person to conduct all interviews. We directly decided against sending out surveys, because these are filled out in a subjective manner which makes comparison of answers difficult – or even impossible. Another positive spin-off from the face-to-face benchmarking 1-2 hours interview sessions is that they trigger good-will and induces a grass-root atmosphere, which is very important for the success of the CDIO implementation.

Syllabus outcomes

As mentioned above learning objectives have recently been adopted in the course material. Typically, faculty is focused on skills in the Section 1 of the CDIO Syllabus, but without clear reflection or attention the teachers also are aware of Sections 2-4. Clearly, the curriculum material and learning objectives illustrate that all elements of the CDIO Standard do not receive equal amounts of attention. Often existing initiatives on Sections 2-4 could be better flagged or signaled in the curriculum material. Again in some courses the focus on skills from Syllabus Section 2-4 is completely absent.

Design-Build Experiences

This program have already installed project work on its first 4 semesters. These projects are mainly teacher controlled in the beginning, but become student governed towards the senior semesters. The project work helps to integrate the teaching and learning given in various classes on the same semester. But there is not any strict emphasis on whether the projects carry any Design-Build experiences. Mainly the projects will focus on the Design phase and more weakly relate to both Conceive and Implement. However the conceive part can easily be applied to many problems within chemical engineering simply by stating more open ended problems. It is more difficult to go into the implement phase. First of all there is a safety issue in chemical engineering. Working in a chemistry lab can be dangerous, and overall safety precautions apply. This mainly means that an Implement stage is difficult to obtain early in the program (unless we simulate an Implement stage in Virtual Laboratories!), but it should be possible also to offer this type of project for mature students (semester four or later). Of course, Design-Build projects do not offer themselves as readily as maybe in mechanical engineering, because many chemical processes do require expensive equipment of pilot scale facilities. Anyhow, on a lab scale level many interesting projects should be possible.

Enhancement of Faculty CDIO Skills

A very important part of implementing the CDIO initiative is to talk about it at faculty meetings and workshops in order to educate colleagues on CDIO and make them aware of – and maybe even enhance their own CDIO skills. Interestingly, two kinds of opposition can be identified here, which documents that it is not always easy to implement a new way of thinking – like the CDIO Initiative. First of all there is a deeply grown reluctance against curriculum changes. At least in Denmark the curriculum changes every now and so often due to external reasons which inflict on the education. These changes normally have a mundane origin, and are very unpopular amongst the teaching faculty. The danger here is that some faculty members experience that CDIO is yet another curriculum change and automatically go into opposition or become reluctant. Secondly, some of the elements focused upon by the CDIO concept may already be present in the engineering program, but in a way which is not presently visible to an outsider, i.e. someone who is not involved in the course as a student or a teacher. In this case the faculty also becomes defensive and reluctant. This second type of opposition is a blessing in disguise and offers the opportunity to be turned around to support.

From approximately 24 months of experience of talking to colleagues and others about the CDIO Initiative, it is clear that it is difficult to catch the attention of a passive audience. One of the reasons for this is due to the name: “CDIO”. It does not mean anything and does not carry information to the outsider. As an acronym it does have an origin and a nice explanation, but for dissemination purposes the acronym serves very badly. Colleagues can hardly recall the four letters after a first introduction, because there is no meaning to the letters (in their memory), and they have a very hard time reproducing what exactly CDIO is all about.

Conclusion

In order to conclude on the degree of implementing CDIO in our B.Eng. program in Chemistry and Biotechnology we summarize here the status against the seven essential CDIO Standards mentioned above.

- *Standard 1* is fulfilled by a management decision.
- *Standard 2* is in progress as other factors recently dictated the use of learning outcomes, however the present status of these outcomes do not include all four sections of the CDIO Syllabus.
- Presently there is no course-curriculum matrix governing the overall layout of courses and progression of skills and integration of all sections of the Syllabus as described in *Standard 3.* However this program has defined its own Target Syllabus or Competences. A benchmarking process is in progress in order to analyze how this matches the existing curriculum.
- We do not have specific Design-Build experiences, but a series of cross-course projects each semester. With little modification some of these can meet the specification set out in *Standard 5*.
- Presently there is very little awareness of integrated learning experiences described by *Standard 7*, although it does exist in various courses without being advertised or flagged.

- The enhancement of faculty CDIO skills first requires that faculty realizes what CDIO is. In order to fulfill *Standard 9* there must be a constant and prolonged period of information and education of the faculty members – especially because the faculty members come from all parts of campus, and do not have a natural centre.
- Presently the program does not directly asses CDIO skills as described in *Standard 11*, but primarily focuses on disciplinary knowledge.

References

[1] www.cdio.org or email: info@cdio.org.

Biographical Information

Martin E. Vigild is an Associate Professor at the Department of Chemical Engineering, DTU, where he serves on the Educational Committee. He teaches introductory and advanced courses in Materials Science, Colloid and Surface Chemistry, Chemical Product Design and Polymer Engineering. His research focuses on the characterization of structure-property relationships of polymeric and composite systems as well as chemical product design and development of novel materials based on molecular self-assembly. He is the director of the Industrial Research Consortium for Polymers at the Danish Polymer Centre, DTU.

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