

# APPLYING THE CDIO FRAMEWORK WHEN DEVELOPING THE ECIU UNIVERSITY

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## ABSTRACT

The use of the CDIO framework in the development of the ECIU University is presented. The paper discusses the relatively moderate adaptations and modifications of the CDIO Syllabus and Standards that are necessary to make the documents applicable also in this context. Since challenge-based learning (CBL) is central learning format in the ECIU University, special attention is given to the connections between CBL method, the conceive-design-implement-operate sequence and project-based learning, which is central in the CDIO framework. The paper presents both general aspects and examples of the applications and activities within ECIU University and Linköping University (LiU). The main messages of the paper are that the development of the ECIU University will benefit from applying the CDIO framework since it offers references for **what** an education should give, in terms of knowledge and skills, and **how** an education program should be designed. In addition, the components of the CDIO framework require a moderate amount of adaptation to be directly applicable. Examples of the ongoing implementation activities at LiU.

## KEYWORDS

Challenge-based learning, project-based learning, ECIU University, Standards: 1 - 12

## INTRODUCTION

The CDIO framework has existed for around two decades, and it has been used at numerous universities to develop, redesign, and manage engineering education programs. See e.g. Crawley et al. (2014) or CDIO Initiative (2021) for thorough descriptions of the framework and presentations of implementation examples. The CDIO framework was designed for engineering education, but there are examples of extensions and applications of the framework to disciplines outside engineering. Fahlgren et al. (2018) was probably the first example of application within the biomedicine field. Another interesting publication is Malmqvist et al. (2016), where various examples, from different disciplines and countries, of applications of CDIO outside engineering are presented. An additional example is given in Martins et al. (2017).

The aim of this paper is to present the potential and the use of the CDIO framework in the development of the ECIU University, which is an initiative involving eleven European universities to build a common framework for a new European University, and the paper is organized as follows. It starts by giving some background information to the ECIU University project and the CDIO framework, and this is followed by a proposal for the use of the CDIO framework in this context. This is followed by a discussion around some of the key aspects, and how they are related to the CDIO framework namely, how to define the desired learning outcomes, the use of the CBL approach, and faculty development, respectively. The paper ends with some concluding remarks.

## **BACKGROUND INFORMATION**

### **The ECIU University**

The European Union (EU) has launched a huge initiative named the European Universities Initiative, where the aim is expressed as follows: *The aim of this initiative is to bring together a new generation of creative Europeans able to cooperate across languages, borders and disciplines to address societal challenges and skills shortages faced in Europe.* See European Universities (2021). This has led to the formation of many alliances around Europe in order to take on this challenge. One of these alliances has been formed within the network ECIU (European Consortium of Innovative Universities), which was formed in 1997 and consists of eleven universities from eleven countries, and where LiU is one of the participating universities. See ECIU (2021). After an extensive application process the proposals from 17 alliances were approved by EU, and one of them is the ECIU University. The project started in November 2019, and it will run for three years. The courses and challenges within the ECIU University have an emphasis on UN Goals for Sustainable Development (SDG) 11 about *Sustainable cities and communities*. In addition to this, the aim of the ECIU University is to create an interdisciplinary educational environment with large flexibility in both room and time.

### **Organization and Implementation**

The implementation of the ECIU University is a complex task with many persons and functions involved. The ECIU University project is led by University of Twente, and the project is organized in nine work packages (WPs). The leadership for each WP is distributed among the participating universities. The management at each participating university depends on the internal organization, and it will not be discussed here.

The organization within LiU includes a working group consisting of the representatives in the different WPs on European level, a steering group with representatives from the highest LiU management level, students, administrative staff, etc. In addition, there are sub-groups for special tasks, and since LiU is responsible for WP5 about Challenge-based innovation there is a sub-group handling various topics related to this WP. Furthermore, there is a sub-group discussing the creation of an Innovation of Education Lab (IEL), which will be connected to the pedagogical unit of the university. The purpose of the IEL is to support teachers developing their competence within CBL.

## The CDIO Framework

The fundamental aim of the CDIO framework is to educate students who are “ready to engineer” and to raise the quality of engineering programs, see Crawley et al. (2014) and the web site CDIO Initiative (2021). The framework relies on four key components:

- A “definition” of the role of an engineer.
- Clearly defined and documented goals for the desired knowledge and skills of an engineer listed in the document the CDIO Syllabus (2021), which serves as a specification of learning outcomes.
- Clearly defined and documented goals for the properties of the engineering education program collected in the document CDIO Standards (2021), which works as guidelines of how to design a well-functioning engineering education.
- Methods and tools for systematic development and management of education programs.

According to the CDIO framework, see Crawley et al. (2014) page 50, the goal of engineering education is that every graduating engineer should be able to *Conceive-Design-Implement-Operate complex value-added engineering products, processes, and systems in a modern, team-based environment*. This formulation can serve as a definition providing the basis for the entire CDIO framework. Adopting the definition, it is natural to design and run an engineering education program with this in focus. The CDIO Syllabus is a list of the desired knowledge and skills of a graduated engineer. The document can be found via the CDIO web site, and it consists of the following four main sections:

1. Disciplinary 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, societal, and environmental context – The innovation process

Via the sub-sections and sub-sub-sections, the document offers an extensive list of knowledge and skills, which can be used to specify learning outcomes of individual courses or education programs. The CDIO Standards (2021), which also can be found and explained in detail via the CDIO web site, is a set of twelve components that are necessary for designing and running an engineering program that enables the students to reach the desired knowledge and skills. The CDIO framework offers a variety of tools for development and management of education programs, including for example the so-called Black-box exercise and the CDIO Syllabus survey. These tools are described in some detail in Crawley et al. (2014).

## PROPOSED USE OF THE CDIO FRAMEWORK

### Re-phrasing the Starting Point

The starting point in the CDIO framework is the definition of what is expected from a graduating engineer given above and in Crawley et al. (2014). Based on the intentions and scope of the ECIU University a possible corresponding definition could be the as follows. Every graduate from the ECIU University should be able to

*Conceive-Design-Implement-Operate complex value-added solutions to societal challenges in a modern, interdisciplinary, team-based environment.*

in comparison to the original formulation

*Conceive-Design-Implement-Operate complex value-added engineering products, processes, and systems in a modern, team-based environment.*

Based on this characterization of the graduates the next steps will be to carry out appropriate modifications and use of the Syllabus and the Standards.

### **Adapting the CDIO Syllabus**

The CDIO Syllabus serves the purpose of being a reference frame in the process of specifying the desired learning outcomes in terms of knowledge and skills of the graduates of a program. The document was originally presented in Crawley (2001), and it has been used extensively since then, including being translated to several languages. Sections 1 – 3 are general and applicable to most types of education situations. The main challenge is to adapt Section 4 to make it suitable, and without going into the exact wordings it is obvious e.g., 4.1 External, societal, and environmental context and 4.2 Enterprise and business context are highly relevant for the ECIU University situation.

### **Adapting the CDIO Standards**

The second fundamental document of the framework is the CDIO Standards specifying *how* an education program should be designed in order to enable for the students to achieve the desired goals in terms of knowledge and skills. Some of the standards are general and work for almost all types of education, while some are specific for engineering education and need adaptation to suit the ECIU University. A proposed adaptation is shown in Table 1.

Table 1. Left column: The CDIO Standards. Right column: Proposed Standard for the ECIU University.

Standard no.	CDIO	ECIU University
1	CDIO as Context	The Context of the education, as defined in the description of the role of the graduate above
2	CDIO Syllabus Outcomes	ECIU University Syllabus Outcomes
3	Integrated Curriculum	Integrated Curriculum
4	Introduction to Engineering	Introduction to CBL
5	Design-Build Experiences	CBL Experiences
6	CDIO Workspaces	Workspaces for CBL
7	Integrated Learning Experiences	Integrated Learning Experiences
8	Active Learning	Active Learning
9	Enhancement of Faculty CDIO Skills	Enhancement of Faculty Skills related to CBL
10	Enhancement of Faculty Teaching Skills	Enhancement of Faculty Teaching Skills as a coach/facilitator/teamcher
11	CDIO Skills Assessment	Assessment related to CBL
12	CDIO Program Evaluation	ECIU University Program Evaluation

Many of the items in the Standards are very general and hence applicable to almost all types of education programs, while some are more directed towards the type of education. The main similarities and differences can be summarized as follows.

Standard 1: Adoption of the vision stated in the definition of the roles of the graduates. Like in the CDIO framework it is crucial to have vision of the role of the graduates as a basis for the design and development of the education.

Standard 2: The expected learning outcomes of the education, specified using the sections of the Syllabus. Starting from the vision of the roles of the graduates a suitable combination of learning objectives from the sections of the Syllabus is formulated. This topic will be elaborated further in the section *Discussion* section below.

Standard 3: To obtain a high-quality education program, it is very important to design a curriculum with courses and learning activities that “fit together”. This means that the learning objectives of one course match the prerequisites of courses later in the education. This is a big challenge when aiming for an interdisciplinary education with a high degree of flexibility in time and space.

Standard 4: Introduction to CBL. For students not used to CBL it is important to get an introductory course in CBL before taking on bigger and more complex challenges.

Standard 5: CBL experiences. CBL is a key element in the design of the ECIU University, and it will be discussed in some detail in the section *Discussion* below. An initial study of the connections between challenge-based learning and parts of the CDIO framework was also presented in Malmqvist et al. (2015).

Standards 7 and 8: Integrated and active learning is obvious in an education program with a substantial amount of CBL, such as the ECIU University, since it is a highly student active learning format integrating disciplinary knowledge and skills from all sections of the Syllabus.

Standard 9: CBL is a comparatively new learning method, and for faculty not used to this it will be necessary with appropriate training before starting to use CBL.

Standard 10: In addition to the specific aspects of CBL, a continuous improvement of teaching skills is always desirable. Maybe the largest difference is for the teacher to serve as a coach for the student team. Additional aspects of how to handle the faculty development will be mentioned in the *Discussion* section below.

Standard 11: Assessment of knowledge and skills is always a challenge, and since CBL is a new method for many faculty members involved, special attention has to be spent how to assess the skills developed using this method.

Standard 12: It is always very important to have appropriate methods for evaluating the quality of education programs, and this is even more important when designing a, in many ways new and unique, education such as the ECIU University.

The items of the CDIO Standard cover many aspects of the design of an education program, but the list of items is not exhaustive. There have hence been activities within the CDIO Initiative to extend the list with optional standards. See e.g., Malmqvist et al. (2019), where a list of proposed optional standards is given. Out of the optional standards the *Workplace and community integration* and *Sustainable development* are the most relevant, but for the ECIU University context we would like to propose and use *Stakeholder interaction* as an additional optional standard. This will be discussed in some detail below.

## DISCUSSION

As expressed above the most important parts that need to be discussed and developed are the subsections under Syllabus 4, the standards 2, 4, 5, 9, 10, and the proposed optional standard Stakeholder interaction.

### Specifying the Learning Outcomes

The Standard 2 is about specifying the expected learning outcomes, in terms of knowledge and skills, of an education to prepare the students for the intended professional role, and within the CDIO framework this is done using the CDIO Syllabus as reference. The Syllabus is a very comprehensive document with a logical structure, and even though it was originally designed for engineering education examples have shown that it is straightforward to modify it to be useful for other types of education programs. However, there are several other examples of documents with similar purpose at the CDIO Standards. A well-known example is the ABET criteria, and the mapping between these and the CDIO Syllabus is described in Crawley (2001). Another very ambitious work is presented in the project Tuning Educational Structures in Europe, see Tuning project (2021). The project has developed an extensive number of results, and among them one can find a list of 31 generic competences, where most of them can be found among the items in the CDIO Syllabus. One additional example is what is denoted as the twelve 21<sup>st</sup> Century Skills, see e.g., Rotherham and Willingham (2010). The 21<sup>st</sup> Century Skills include for example critical thinking, communication, and collaboration, which all can be found in the CDIO Syllabus. A final example is the eight Key competences for sustainability, defined in UNESCO (2017). Among them one finds collaboration competence, integrated problem-solving competency, and normative competency. It would be an interesting, but challenging, task to try to find mappings between each of the sets of skills and competences, but this is not the aim here. Instead, the key message is that there are many possible references for structuring the desired learning outcomes of an education, and that it, from the perspective of the ECIU University, is important to use a common such reference. An additional message is that a suitably adapted version of the CDIO Syllabus would serve this purpose.

### CBL Experiences

The Standard 4 and 5 are about the use of CBL as learning format. CBL has received considerable attention during the last two decades and there are numerous publications and web sites presenting the fundamental ideas and implementations. See for example Challenge Based Learning (2021) and Membrillo-Hernández et al. (2018). It is not the aim of this paper to give any overview of the topic, and instead we refer to publications in the field. As pointed out by several authors there are both similarities and differences between CBL and problem-based and project-based learning, and there are several suggestions for how to characterize these differences and similarities. However, from the perspective of the ECIU University it is important to, as far as possible, describe the net values, in terms of learning outcomes, that are obtained by using CBL in comparison to problem-based and project-based learning. The additional values of using CBL are often described in general and vague terms, but to give a correct picture of the approach and motivate the use of CBL it is important to express this more clearly. In that process it would be useful to have a common reference when discussion and specifying learning outcomes, as discussed in the sub-section above. An interesting exercise would be to go through the CDIO Syllabus and point out the learning outcomes for which CBL is a more suitable format than other approaches. Such an exercise could also reveal if some learning outcomes should be added to the document.

As mentioned, there are many aspects that are similar, or related, when comparing CBL with the other approaches, and when applying CBL within the ECIU University is that it is important to make use of the big source of experience that is available within the CDIO Initiative and elsewhere. Some of the most important aspects are the following.

### *Work Process*

One proposed work process for CBL consist of three main stages, where each stage consists of three sub-stages:

- Engage – big idea, essential questions, challenge
- Investigate – guiding questions, guiding activities/resources, analysis
- Act – solution, implementation, evaluation

Comparing these stages with the CDIO sequence, i.e. the steps conceive, design, implement, and operate, it is obvious that, even though the wordings are different, there are strong similarities. It starts with a challenge, an idea or an identified need, and results in an implemented solution. The actual implementation and execution of the learning activity can be different, and it involves aspects such as the planning and use of time and other resources, regular meetings with the persons having different roles around the team, and components of assessment.

### *Teamwork*

In CBL, as well as in project-based learning, one of the learning outcomes is to develop the teamwork skills of the students. This is stressed in sub-section 3.1 of the Syllabus, where various aspects of teamwork are listed, such as team formation and roles in the team. In CBL the high degree of inter-disciplinarity will add an extra dimension to the formation and operation of the teams. Within LiU, group contracts have been used for several years in both project-based and problem-based learning activities to support the teamwork. In addition, various tools, and documents for reflection over the lessons learned are used in many of these learning activities. The experiences concerning various aspects of teamwork that have been collected within the CDIO network have the potential to be very useful in the development of the ECIU University.

### *Roles around the Team*

There are several persons with different roles around the team, and the names and tasks of these roles are not unique and can have slightly different meaning in different contexts. The *challenge provider* represents the stakeholder proposing the challenge. Even though there are differences there are some similarities with the role of the sponsor/customer role, which is used in some project-based courses. See for example Svensson and Gunnarsson (2012). A key aspect is the role of the teachers, and in CBL it is clearly stated that the role of the teacher should be more of a coaching role. Several names have been proposed for this role, including *coach* and *facilitator*. Within the ECIU University word *teamcher* has been proposed to stress the close interaction between the teacher and the team. There are also connections to the word *supervisor*, used in project-based and problem-based learning. However, it should be stressed that it is how the person acts in the interaction with the students that is important, and not the name of the role, but to reduce the risk of confusion it is of value to have a common vocabulary.

### *Choice and Formulation of Challenge/task*

In CBL initial effort is invested on the Engage-phase which involves the identification and forming of challenges that are appropriate for a specific course, and some important characteristics are summarized here. A qualified challenge must be able to engage students and be relevant. In the ECIU University the framework of SDG 11 will be a guiding criterion for relevance. The challenge also needs to be complex, contain multiple areas of knowledge base (interdisciplinary), be scalable, have innovation potential and offer possibility for the students to find multiple solutions. The challenge provider is central in the identification and forming of the challenge, but since the aim is also to motivate the students, there is a need for discussions between the challenge provider and the student group. A final fine-tuned challenge is then formulated to represent the starting point for the learning in the course. In comparison with CDIO, due to the Engage-phase in CBL the process starts earlier than the CDIO-process.

### *Communication*

Whenever the expected learning outcomes from an education is specified, see e.g., Section 3 of the CDIO Syllabus, the issue of communications comes up, and so also within CBL. This includes written and oral communication in various forms, as well as the use of electronic tools for communication, and also here the CDIO network offers extensive experience.

### **Faculty Development**

As pointed out in Standards 9 and 10 the competence development of the teachers is a key component in all types of education, and so also when it comes to CBL. Several activities related to faculty development around CBL have been carried out or are in the implementation phase. ECIU University is of course one driver behind the need for faculty development concerning CBL, but the interest in CBL at LiU is increasing in general. During the fall semester of 2020 the CBL-based course Sustainable development (3 ECTS) was given for the first time. As a preparation a series of workshops were arranged for the teachers in the course, and the workshops were carried out using a CBL format. The pedagogical unit of the university is preparing a CBL course open for all teachers at LiU, and it will be given during the first half of 2021. The course will make use of experiences gained during the development and execution of the Sustainable development course. The pedagogical development group at the Faculty of Science and Engineering at LiU is funding a development project aiming at developing the use of CBL within the engineering education programs at LiU. The team in charge of the project is based at the unit for Innovation and Entrepreneurship, but the aim of the project is to also reach teachers and courses in other disciplines.

Malmqvist et al. (2015) point out that there are tight links between CBL and both problem-based learning and project-based learning, and it is claimed that CBL can be seen as a step forward from these approaches. Since LiU has a long and solid background in both problem-based and project-based learning, there is a strong foundation for faculty development in CBL. LiU was a pioneer concerning the use of problem-based learning within the education programs at the Faculty of Medicine and Health Sciences, and via, primarily, the participation in the CDIO Initiative, there is a solid experience in project-based learning.

Another big source of experience is the findings from the so called "InGenious course", with the official name InGenious - Cross Disciplinary Project (8 ECTS). The course has its background in what was called Demola, and it has been running for approximately ten years.

Even though not explicitly stated so it has most of the key features of CBL course. The InGenious organization is tightly connected to the ECIU University, and more information can be found via InGenious (2021).

### **Stakeholder Interaction**

We here propose the optional standard Stakeholder interaction. Interaction with the surrounding society is an important factor for all types of education to ensure the relevance of the education. For the ECIU University and the strong emphasis on CBL the stakeholder interaction is even more important. A key idea of the ECIU University is to bring in challenges from various types of external stakeholders, including both companies and public organizations. A first step in this direction was taken in February 2020 when a so-called Society Quest was arranged at LiU. The participants at the event came from the participating universities in the ECIU network, but also stakeholders from the public sector, e.g., regions or municipalities, connected to the partner universities. The event led to the formation of a database over challenges to be dealt with in the CBL-activities at the different universities. A pilot project to find suitable formats for interaction with industry stakeholder is carried out in collaboration with Toyota Material Handling, that has a site with both R&D and production in the geographical neighborhood of LiU. The pilot is however more focused on research collaboration.

## **CONCLUSIONS**

The use of the CDIO framework in the development of the ECIU University has been discussed. The paper has presented the adaptations and modifications of the CDIO Syllabus and Standards that will be necessary. The connections between CBL and the conceive-design-implement-operate sequence and project-based learning have been discussed. The main conclusions are that, even though some modifications will be needed, the CDIO framework is a very useful in the development of the ECIU University. The paper has also presented various aspect of the implementation of the ECIU University at LiU.

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