LARGE SCALE USE OF THE CDIO SYLLABUS IN FORMULATION OF PROGRAM AND COURSE GOALS

Svante Gunnarsson, Ingela Wiklund, Tomas Svensson, Annalena Kindgren, Sten Granath
Linköping University
Linköping, Sweden

Abstract
A large scale application of the CDIO Syllabus in formulation of course and program goals is presented. The application involves all programs and courses within the engineering education at Linköping University. Key components in the work are course level ITU-matrices for mapping of the course contents to the CDIO Syllabus, and a suggested way to organize suitable verbs for formulation of learning outcomes according to the sections in the CDIO Syllabus.

Keywords: CDIO Syllabus, program goals, course goals

Introduction

An essential component in the so called Bologna process is the formulation of learning outcomes of individual courses as well as of entire education programs. The board of The Institute of Technology at Linköping University has decided that the new program and course plans, including the formulation of learning outcomes, shall be based on the CDIO Syllabus. The process hence involves approximately 25 education programs of various types, more than one thousand courses and several hundred faculty members. This paper presents how the CDIO Syllabus has been used as the basic document in this process, how various tools and methods have been introduced to support the development of program and course goals, and how the development process is managed.

Working with goals for programs and courses involves both the formulation of the goals and mechanisms for verification that the goals are fulfilled. The work that will be presented here involves both aspects, but the focus will be on mechanisms that can be used to check if the goals are met. The process can be seen as a bottom-up approach where the contents and goals of courses are investigated in a systematic way. Using the phrase “large scale” in the description of the work is motivated by the fact that all faculty members responsible for a course have had to consider the CDIO Syllabus and reflect upon the contents and goals of his/her course with this background.

The CDIO Syllabus has been used in several ways to deal with course and program goals ever since the start of the CDIO Initiative. Results from the work carried out during the first years of the Initiative are presented in [1] and [2]. A more recent publication in the same area is given in [3].

The CDIO Syllabus

There exist a large number of suggestions for how to specify the desired knowledge and skills of a graduating engineer, and a survey of some of the examples is given in [3]. In the Swedish system for higher education the overall most important document is Högskoleförordningen (The Degree Ordinance) [5], which specifies expected knowledge and skills for various types of educations, including engineering programs. Comparing the structure and the formulations of The Degree Ordinance with the CDIO Syllabus shows that the CDIO Syllabus has a more logical structure and is easier to adapt to different types of programs. It can also be found that the CDIO Syllabus covers the goals listed in The Degree Ordinance almost completely.

The CDIO Syllabus has been a fundamental document ever since the start of The CDIO Initiative. The Syllabus itself and a thorough description of its background can be found via the web page of The CDIO Initiative [4]. It is structured in the following four sections:

1. Technical knowledge and reasoning
2. Personal and professional skills and attributes
3. Interpersonal skills: Teamwork and communication
4. Conceiving, designing, implementing and operating systems in the enterprise and societal context

The CDIO Syllabus represents a long list of desired knowledge and skills, but the extensive use of the CDIO Syllabus in the development of new program and course plans within Linköping University has shown that there can be a need for some extensions of the original version of the Syllabus.

- The Degree Ordinance puts strong emphasis on sustainable development, and this is expressed by the formulation "… including economical, social and ecological sustainable development". These aspects are naturally covered by Section 4.1 in the Syllabus, but in order to make this requirement more visible the quoted formulation from the Degree Ordinance has been included in the local version of the Syllabus.
- The Industrial Engineering and Management program is one of the biggest engineering programs at Linköping University. The program has specializations in for example marketing, logistics and financing. In the program plan it is expressed that one of the main goals for the engineers graduating from this program is to be able to be leading in the process of implementing the outcome of the engineering work into business activities. This can be seen as an extension of the scope of the role of an engineer as it is expressed in the original version of the Syllabus, and to stress this fact the title of Section 4 of the Syllabus has been modified accordingly.
- The Institute of Technology within Linköping University has also a number of educational programs in natural sciences (physics, chemistry, biology, and mathematics). For these programs the product development and system building context is less appropriate, and for this purpose a modified version of Section 4 has been developed with this type of programs in mind. The product development framework is there replaced with a more research oriented one.

Course level ITU-matrices

The new course plans and specifications of learning outcomes are supposed to handle various aspects of a course and its role in the program. The most important ones are:

- Specification of learning outcomes for knowledge and skills.
- The progression with respect to previous courses, and classification of courses on bachelor or master level.

In order to deal with these aspects it has been decided to use the Introduce-Teach-Utilize (ITU) concept as discussed in [1]. In practice this means that, for each individual course, the faculty member responsible for that course is supposed to fill in a so called ITU-matrix, of the type shown in Figure 1. In the ITU-matrix the I-column represents topics that are introduced in the course, but not subject to examination. The T-column represents knowledge and skills that are taught in the course and also subject to examination. Finally, the U-column represents knowledge and skills that have been acquired in previous courses and are considered to be pre-requisites. These will of course be included indirectly in the examination, like e.g. mathematics in an engineering course. See also [3] for details on the use of the ITU-concept. In order to keep the effort at a reasonable level it was decided to work at the X.Y level of the Syllabus. In the process of filling in a matrix the entire Syllabus can be used in order to find examples of what a particular level represents.

TSRT19, Automatic Control I		I (Introduce)	T (Teach)	U (Utilize)	Comments
1	**TECHNICAL KNOWLEDGE AND REASONING**				
1.1	KNOWLEDGE OF UNDERLYING SCIENCES			X	calculus, algebra, physics
1.2	CORE ENGINEERING FUNDAMENTAL KNOWLEDGE	X	X		analysis and design of control systems
1.3	ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE				
2	**PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES**				
2.1	ENGINEERING REASONING AND PROBLEM SOLVING	X	X		modeling of systems and signals
2.2	EXPERIMENTATION AND KNOWLEDGE DISCOVERY		X	X	experimentation using laboratory processes
2.3	SYSTEM THINKING	X	X		general thinking throughout the course
2.4	PERSONAL SKILLS AND ATTITUDES			X	individual work during problem solving
2.5	PROFESSIONAL SKILLS AND ATTITUDES				
3	**INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION**				
3.1	TEAMWORK			X	laboratory exercises in groups of 2
3.2	COMMUNICATION			X	written report
3.3	COMMUNICATION IN FOREIGN LANGUAGES	X		X	introduces English control vocabulary
4	**CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT**				
4.1	EXTERNAL AND SOCIETAL CONTEXT	X			the role of control in systems, products
					and processes
4.2	ENTERPRISE AND BUSINESS CONTEXT				
4.3	CONCEIVING AND ENGINEERING SYSTEMS	X	X		fundamental limitations in control systems
4.4	DESIGNING	X	X		design of control systems
4.5	IMPLEMENTING	X			implementation on laboratory processes
4.6	OPERATING				

Figure 1. Example of a course level ITU-matrix.

It should be stressed once more that the ITU-matrix used in this way will serve as an analysis tool where the current contents and organization of a course is described.

In the original work [1] the analysis of the courses was done using interviews. Such a procedure can be used in a smaller scale, but becomes impossible when the number of courses becomes large. An advantage with the interview method is that the faculty member will be helped in the understanding of the topics in the Syllabus. Letting the faculty members fill in the matrices themselves, which is the only realistic alternative when the number of courses is large, is that it gives a reason to get familiar with and study the CDIO Syllabus in detail.

Specification of learning outcomes

The central part of the new course plans that result from the Bologna process is the specification of learning outcomes. A consequence of having the CDIO Syllabus as background for all work with program and course plans is that also the specification of learning outcomes has to be done in this context. In order to support to faculty members in this process a table, see Table 1 in the Appendix, has been formulated. In the table the sections in CDIO Syllabus are combined with verbs that are arranged in taxonomy-like structure. The table does not follow any particular taxonomy, but has been inspired by several sources. For each of the four main sections of the CDIO Syllabus and the five levels of the taxonomy some examples of verbs are suggested for use in the formulation of learning outcomes. To the best of our knowledge this is the first attempt to do this combinations and the proposed table shall be seen as an initial preliminary attempt. A related, but not entirely equivalent, example is the rating of expected proficiency that was used in the proficiency survey, as presented in [2].

Program level ITU-matrix

One use of the course level ITU-matrices will be to use them as building blocks when forming ITU-matrices on the program level, i.e. to use the ITU-matrices for the courses to form a large ITU-matrix for an entire program. An initial example of such a program matrix can be found in [1], which presents a program level matrix for the Applied Physics and Electrical Engineering program at Linköping University. The program matrix was generated as a part of the curriculum benchmarking work during the initial phase of the CDIO Initiative. As a complement to that example Figure 2 shows the program level ITU-matrix for the Mechatronics specialization of the Applied Physics and Electrical Engineering program. The specialization runs, in the version presented here, from the last part of year three through the entire fourth year of the program. Some observations can be made from this example:

- Since most of the courses in the specialization are on the Master level it is common to have a U (Utilize) in the column 1.1 (Knowledge of Underlying Science). There are however courses where all three stages (ITU) have been marked in column 1.1. It can be noted that these courses are given by the same department, so some kind of common thinking among the faculty members can be the background for this choice.
- The columns 1.2 (Core engineering fundamental knowledge), 1.3 (Advanced engineering fundamental knowledge), 2.1 (Engineering reasoning and problem solving), and 2.3 (System thinking) are the ones with the highest number of T's.
- The skills in Conceive, Design, Implement and Operate are most visible in the project course in Automatic Control, but they can also be found in courses like Digital Signal Processing and Automotive Control Systems respectively.
- Operate does not belong to the learning outcomes in the courses in this specialization.

- There is a T in column 4.1 (External and Societal Context) for the course Automotive Control Systems. This is explained by the fact that the course puts a strong emphasis on modeling of combustion engines and design of control system for minimization of emissions in order to meet regulations in this area.

Mechatronics	1.1	1.2	1.3	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	4.1	4.2	4.3	4.4	4.5	4.6
Analytical mechanics	U		T	TU		T	T		U	U	U						
Modeling and simulation	U	TU	IT	T	TU	TU	U		U	U		I		IT		IT	
Automotive control systems	U	U	T	U	U	TU		U		U		T		TU	TU	TU	
Applied therm. and fluid dynamics	U	TU		T			I		I	I							
Digital signal processing	U	TU	IT	T	TU	TU	U					I	I	IT		IT	I
Control theory	U	U	T	T	TU	TU	U		U	U		I		T	T	I	
Real time and concurrent progr.	U	TU	I	T	U	T	T		U	U	U			T	T		
Project - Applied mathematics	TU			TU	TU		TU	TU	U	IT							
Automatic control project course	U	U	TU	TU	U	TU	TU	TU	TU	TU	U	I	I	TU	TU	TU	I
Flight dynamics	ITU	TU					TU			U							
Multi body dynamics and robotics	U		T	T					I	U							
Computational fluid dynamics	ITU			T	T					U							
Vehicle dynamics and control	U	U	T	T		T			U	U							
Aerodynamics	ITU	TU		T													
Diagnosis and supervision	U	U	T	T		T				U							
Digital control	U	IT		IT	TU	IT	U		U	TU		I		IT	IT	I	

Figure 2. Example of a program level ITU-matrix.

Use of the Documents

The overall aim of using the methods and documents presented here is to have systematic methods to verify that the education programs fulfill the requirements in The Degree Ordinance. A possible procedure for doing could be as follows:

- Select a topic in the Degree Ordinance.
- Map the topic in the Degree Ordinance to the corresponding column(s) in the CDIO Syllabus.
- Identify the courses in the corresponding column(s) in the program ITU-matrix.
- For the courses marked in the columns use the course level ITU-matrices and the course plans, including the learning outcomes, to identify the relevant course components, learning outcomes and examination activities.

Some Experiences
The Bologna process and the adaptation of the engineering education to the new structure can be seen as a huge development project, where the formulation of new program and course plans represents a sub-project of significant size and involves a lot of people. Using such a viewpoint is useful when collecting some of the experiences so far. First, it is important to have a clearly defined project leader with the ability to organize the work and motivate all people involved. Second, it is important to give all people involved clear instructions and specifications about what to deliver and when it should be delivered. Third, it is important to involve and motivate persons at strategic positions both within the departments, particularly the Directors of Studies, and within the program boards. These persons can then give support in the process of motivating the faculty members and answering questions.

On a more detailed level a number of important observations can be made concerning the use of the CDIO Syllabus as basis when working with program and course plans in such a large scale. The main observations are:

- The process of formulating detailed learning outcomes is a new and sometimes big step for many faculty members, irrespective if the CDIO Syllabus is used or not.
- The process of formulating learning outcomes can act as an inspiration for a fruitful discussion concerning course contents, learning outcomes and examination issues.
- A thorough education process is required in order to initialize the development work.
- It is a reasonable effort to fill in the ITU-matrix on the X.Y. level, but it is necessary for the faculty members to have the topics on the X.Y.Z.-level available, in order to get guidance about how to fill in the matrix.
- Examples of filled in ITU-matrices, “approved” by the project leader, from various areas are very useful
- Clear definitions for when to put an I, T or U in the matrix are important.
- It is important that there are resource persons available in order to answer general question concerning the formulation of learning outcomes, as well as question like “How much do I need to spend on this topic in order to motivate an I in the ITU-matrix?”
- When the faculty members fill in the ITU-matrices it is unavoidable that the outcome will depend on the interpretations done by that particular person.

Conclusions
A large scale use of the CDIO Syllabus as a basis for description of program and course goals has been reported. The essential tools in this process have been so called ITU-matrices on both program and course level. To support the formulation of learning outcomes with the CDIO Syllabus as background a number useful verbs have been organized according to the sections in the Syllabus and a taxonomy-like structure. Some experiences of the development process have been reported.

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Biographical Information

Svante Gunnarsson is Professor in Automatic Control and Chairman of the Program Board for Electrical Engineering, Physics and Mathematics at Linköping University, Sweden. His main research interests are modeling, system identification, and control in robotics.

Ingela Wiklund is Director of Studies for the Program Board for Electrical Engineering, Physics and Mathematics at the Dean's Office, Institute of Technology, Linköping University. She is MSc in Applied Physics and Electrical Engineering from Linköping University.

Tomas Svensson is an Associate Professor in Computer Engineering at Linköping University. He his responsible for various courses in Computer Engineering and in particular the Project Course in Electronics. He is also one of the developers of the project model LIPS. He is MSc in Applied Physics and Electrical Engineering from Linköping University.

Annalena Kindgren is Director of Studies for the Program Board for Chemistry, Biology, and Biotechnology at the Dean's Office, Institute of Technology, Linköping University. She is MSc in Scientific Subjects Education from Linköping University.

Sten Granath is a Director of Studies for the Program Board for Industrial Engineering, Management and Logistics at the Dean's Office, Institute of Technology, Linköping University He is MSc in Applied Physics and Electrical Engineering from Linköping University.

Corresponding Author

Svante Gunnarsson
Department of Electrical Engineering
Linköping University
SE-58183 Linköping
Sweden
+46-13-281747
svante@isy.liu.se

Appendix

Table 1. Verbs for formulation of learning outcomes

Level	CDIO 1.x	CDIO 2.x	CDIO 3.x	CDIO 4.x
1	reproduce facts	reproduce facts	reproduce facts	reproduce facts
2	list, quote, describe, define	seek information, identify	seek information, quote, describe	seek information, describe, identify
3	analyze, ex-plain, exemplify, summarize knowledge, calculate	analyze, explain, use, perform, exemplify	follow accepted rules, perform an agreed-upon task, summarize information, explain, communicate according to given conditions, argue, defend	analyze, survey
4	model, solve, implement, derive, predict, apply, choose a method or solution, optimize demonstrate, show	model, estimate, take the initia-tive, apply, relate, separate, convert	take the initiative, do several agreed-upon tasks in parallel, take part in the process of formulating common rules, handle conflicts, structure and present infor-mation, choose a form and method for communication	design/construct, calculate, model, implement, predict, solve, apply, optimize, demonstrate, show motivate
5	evaluate, prove, verify, structure, generalize	assess, conclude, evaluate information, plan and prioritize, verify, reflect, criticize, decide, apply methods and theories in new contexts	lead, plan, evaluate, reflect, criticize, motivate and inspire, communicate in new contexts	plan, specify, integrate, synthesize, evaluate, reflect, have perspective, verify, assess, follow-up and modify