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USE OF CDIO STANDARDS IN SWEDISH NATIONAL EVALUATION OF ENGINEERING EDUCATIONAL PROGRAMS

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ABSTRACT

In this paper, we report on a large-scale application of the CDIO standards, involving approximately 100 educational programs. The context is the Swedish national evaluation of its "civilingenjör" engineering degree programs made by the Swedish National Agency for Higher Education (Högskoleverket, HSV). In the paper, we first briefly describe the CDIO standards focusing on the role as a support for continuous program development. We then present the self-evaluation materials used in the HSV evaluation and account for HSV's motives for including the CDIO standards evaluation in the self-evaluation package and for the modifications made compared to the original CDIO standards. We then discuss the results from a survey and an interview study directed to the program managers that have applied the CDIO standards in the HSV evaluation. The questions in the survey aim to investigate the respondents' view of the relevance, benefits, limitations and ease of use of the CDIO standards. The questions are aimed both at the overall level – the body of standards – as well as at the level of single standards.

INTRODUCTION

The CDIO model [1, 2] is a model for engineering education that stresses that the product lifecycle – Conceive-Design-Implement-Operate (CDIO) – should form the framework for the design of the engineering educational program. The educational design process is guided by the CDIO standards, a set of twelve principles that characterizes this educational model as well as general good practice in education [3]. The fulfillment of each standard is measured by a five-level scale, thus also providing a tool for continuous improvement. So far, the CDIO standards have been applied for a limited number and range of educational programs, essentially the collaborators in the CDIO Initiative [1, 2]. In this paper, we report on a large-scale application of the CDIO standards, involving approximately 100 educational programs. The context is the Swedish national evaluation of its "civilingenjör" engineering degree programs. These programs are 4 ½ year integrated engineering programs roughly equivalent to Master of Science or Diplom-Ingenieur degrees. The quality of these programs is evaluated by the Swedish National Agency for Higher Education (Högskoleverket, HSV) every six years.

In the paper, we first briefly describe the CDIO standards focusing on the role as a support for continuous program development. We then present the self-evaluation materials used in the HSV evaluation and account for HSV's motives for including the CDIO standards evaluation in the self-evaluation package and for the modifications made compared to the original CDIO standards. We then discuss the results from a survey and an interview study directed to the program managers that have applied the CDIO standards in the HSV evaluation. The questions in the survey aim to investigate the respondents' view of the relevance, benefits, limitations and ease of use of the CDIO standards, as well as map out the measures that have been taken by the programs in response to the evaluation results. The questions are aimed both at the overall level – the body of standards – as well as at the level of single standards. The quantitative data from the survey is complemented with qualitative data gained from interviews with selected program managers, carefully chosen to represent program types that have not earlier applied the CDIO standards.

THE CDIO STANDARDS

The CDIO standards (Figure 1) define the essential characteristics of an engineering program that has adopted the CDIO model of engineering education reform [3]. The 12 standards were developed in response to the request from programme stakeholders to be able to recognize CDIO programmes and their graduates. The 12 CDIO standards serve as guidelines for educational program reform and evaluation, create benchmarks and goals with worldwide application, and provide a framework for continuous improvement. The 12 CDIO standards address program philosophy, curriculum development, design-build experiences and workspaces, new methods of teaching and learning, faculty development, and assessment and evaluation. Seven are considered essential because they distinguish CDIO programs from other educational reform initiatives; five supplementary standards significantly enrich a CDIO program and reflect best practice in engineering education.

Standard 1 — CDIO as Context*
Adoption of the principle that product and system lifecycle development and deployment — Conceiving, Designing, Implementing, and Operating — are the context for engineering education

Standard 2 — CDIO Syllabus Outcomes*
Specific, detailed learning outcomes for personal, interpersonal, and product and system building skills, consistent with program goals and validated by program stakeholders

Standard 3 — Integrated Curriculum*
A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills

Standard 4 — Introduction to Engineering
An introductory course that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills

Standard 5 — Design-Build Experiences*
A curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level

Standard 6 — CDIO Workspaces
Workspaces and laboratories that support and encourage hands-on learning of product and system building, disciplinary knowledge, and social learning

Standard 7 — Integrated Learning Experiences*
Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills

Standard 8 — Active Learning
Teaching and learning based on active experiential learning methods

Standard 9 — Enhancement of Faculty CDIO Skills*
Actions that enhance faculty competence in personal, interpersonal, and product and system building skills

Standard 10 — Enhancement of Faculty Teaching Skills
Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning

Standard 11 — CDIO Skills Assessment*
Assessment of student learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge

Standard 12 — CDIO Program Evaluation
A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement

Figure 1: The 12 CDIO standards that define the distinguishing features of a CDIO program. An asterisk (∗) defines the seven essential standards.

The determination of a program's progress towards the CDIO standards is accomplished through self-evaluation. An excerpt of the lay-out of the self-evaluation form is shown in Figure 2. The fulfillment of each standard is measured by a five-level scale, which is used to rate the progress towards the planning, implementation and adoption of each CDIO standard. The rubrics of the five-level scale are stated in Figure 3. Self-evaluation using the 12 CDIO standards and the five-level rating scale provides a tool for monitoring of improvements via a series of evaluations where overall program improvement can be made visible through an increase in total score.

Compliance with CDIO Standards

Institution:
Program:
Evaluators:
Date:

	CDIO STANDARD	EVIDENCE OF COMPLIANCE	RATING	ACTIONS
1	Adoption of a mission statement that includes the principle that product and system lifecycle development and deployment – Conceiving, Designing, Implementing and Operating - are the context of engineering education*			
2	Specific, detailed goals for personal, interpersonal and product and system building skills, consistent with program mission and validated by program stakeholders*			
3	A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal and product and system building skills*			
4	An introductory course that provides the framework for engineering practice in product and system building, and introduces essential…			

Figure 2: Excerpt from CDIO self-evaluation form.

	0	No initial -level plan or pilot
	1	Initial -level plan and pilot implementation at the course or leve
	2	Wel -developed -level plan and prototype implementation at course program
	3	Complete and adopted -level plan and implementation of the plan course and program levels
	4	Complete and adopted -level plan and comprehensive implementation course and program levels, with continuous improvement ocesses in

Figure 3: Rating scale used in self-evaluation with the CDIO Standards.

SWEDISH NATIONAL EVALUATION OF ENGINEERING PROGRAMS

The Swedish National Agency for Higher Education [4] is the government agency which is responsible for the evaluation of the quality of university education in Sweden. Subjects and professional degree program are evaluated each six years. HSV also evaluates applications from universities and colleges to start a particular program on the bachelor, master and doctoral levels. The purposes of the quality evaluations are to

- Contribute to the universities internal quality and development work
- Audit whether a particular educational program meets the requirements stated in the Swedish university law and regulations
- Give information to prospective students
- Inform the government of the quality of higher education
- Give the public insight into the outcomes of investments made in the university sector

An evaluation is a three step process:

1. **Self-assessment.** The university that offers a particular educational program first does a self-assessment. The self-assessment implies that the university analyzes its programs, and identifies strengths and weaknesses. The self-assessment is based on a set of questions stated by the HSV. There is a common base for all self-assessments across the university sector, complemented by domain-specific questions.
2. **Site visits by an external review panel.** The self-assessment report is then studied by an external review panel and discussed with the program management, faculty, students and university-level staff at a site visit. The purpose of the site visits is to confirm and deepen observations made from studying the self-assessment reports. This results in a review report which may include compulsory requirements for changes, which if not implemented may lead to that the university's right the offer the degree in question is revoked. The external review panel is composed by individuals with academic and pedagogical backgrounds from Swedish and international universities. There is also a student representative. Representatives with industry or government experience may be part of the panel.
3. **Follow-up.** After all programs have been evaluated, a report is published by HSV analyzing the total state of education within the sector in question in Sweden. A conference is arranged to discuss the findings and recommendations of that report. Finally, a follow-up is made 1-3 years after the evaluation, with the purpose of assessing the effects of the evaluation's recommendations.

In 2005, an evaluation of the "civilingenjör" engineering degree programs takes place. These programs are 4 ½ year integrated engineering programs roughly equivalent to Master of Science or Diplom-Ingenieur degrees. There are about 100 such programs in Sweden at roughly 10 different universities. The programs range across all domains of science and engineering, including engineering physics, mechanical engineering, information technology, industrial engineering and more. The basic structure of the self-assessment questions posed to these programs is indicated in Figure 4. The questions are divided into university-level questions and program-level questions, and then further decomposed into questions related to pre-conditions, results and processes. There are about 20 university-level questions and about 50 program-level questions. One example of a university-level question is *"How does the university use knowledge about and experiences from graduated students in its educational planning?"* [4]. An example of a program-level question is *"Describe the program in terms of specific goals and profile(s). Account for the considerations made when designing the program. Attach the program plan."* [4].

These questions are similar to those posed to programs in other sectors, but also include some domain-specific modifications. However, for this evaluation, HSV also decided to add an overall program assessment component to the questions [5]. The purposes were to

- Complement the responses to the basic questions in order to attain a more comprehensive, overall assessment of the university and program
- Give the external review panel an additional instrument for its analysis and evaluation
- Provide the universities/programs with an instrument that can be applied as a basis for future continuous improvement efforts

The CDIO standards and the associated self-assessment tools (Brodeur & Crawley [3]) were chosen for this purpose. The application essentially followed that suggested by Brodeur & Crawley. However, a number of modifications were also made to adapt the standards to the context: The standards were re-formulated to avoid the use of the acronym "CDIO" while keeping the corresponding content. The programs were also given an option to re-state Standard One, enabling them to replace the "product and system development" context with another more fitting to their particular program. Finally, there was no summary of a total score, the intention being to avoid that programs would use their total score as a basis for some kind of ranking.

In order to facilitate application of the CDIO standards self-assessment procedure, the programs were supplied with a set of instructional documents (translated into Swedish), including

- The description of the CDIO standards
- A set of headings and topics for a program goal statement, essentially a condensed version of the CDIO syllabus [6]
- A template for the evaluation form
- Two examples of CDIO self-assessments

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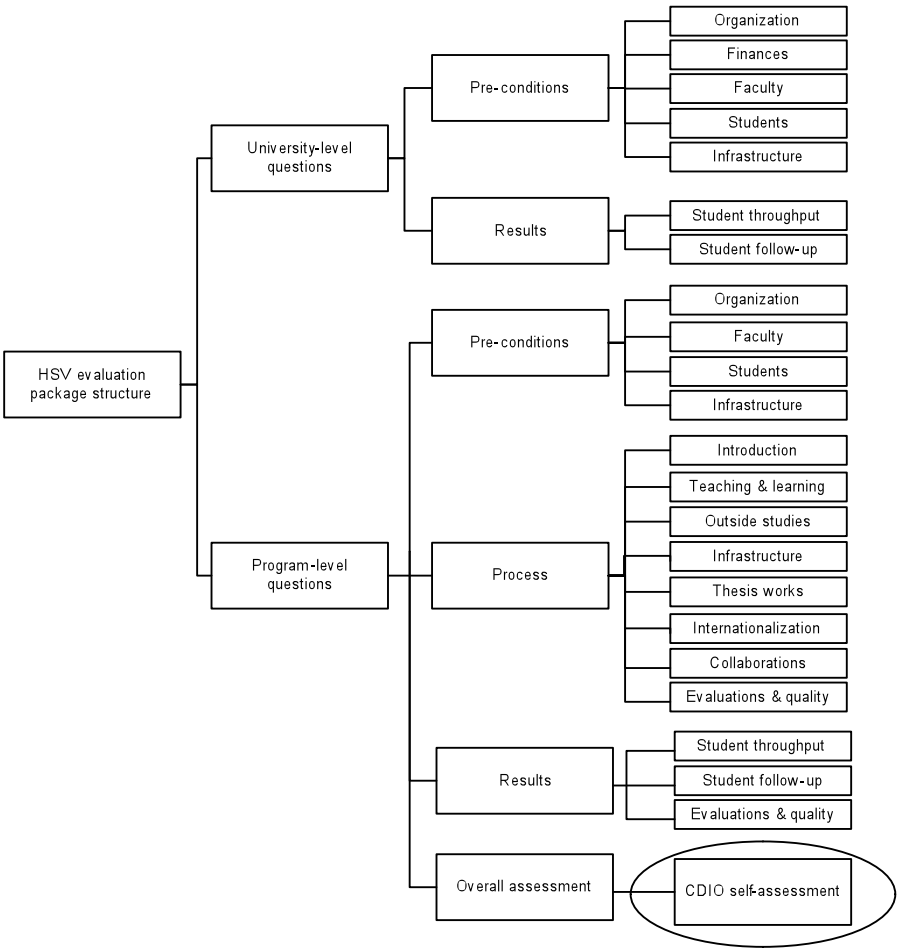

Figure 4: Structure of HSV self-assessment questions package.

RESEARCH METHOD

In order to investigate the respondents' view of the relevance, limitations and ease of use of the CDIO standards a survey and an interview study was carried out. The survey questionnaire was divided into five parts, see Figure 5. The first part covers background questions concerning what type of program the respondent represents and previous knowledge of the CDIO Initiative. In the second and third part, the respondents were asked to judge the ease of understanding, the ease of use, the relevance and the applicability of the overall CDIO standards as well as each individual CDIO Standard. The fourth part of the questionnaire covered the rating-scale, and finally the respondents were given the opportunity to give general comments on positive and learning aspects of the CDIO standards and also suggest improvements to the standards.

The quantitative data was complemented with qualitative data obtained from interviews with selected program managers, chosen to represent program types that have not earlier been involved in the CDIO Initiative.

The response rate of the survey was approximately 30 % covering a broad spectrum of different engineering programmes. Five interviews were carried out by the same interviewer, at two different universities. The interviews were recorded and transcribed verbatim.

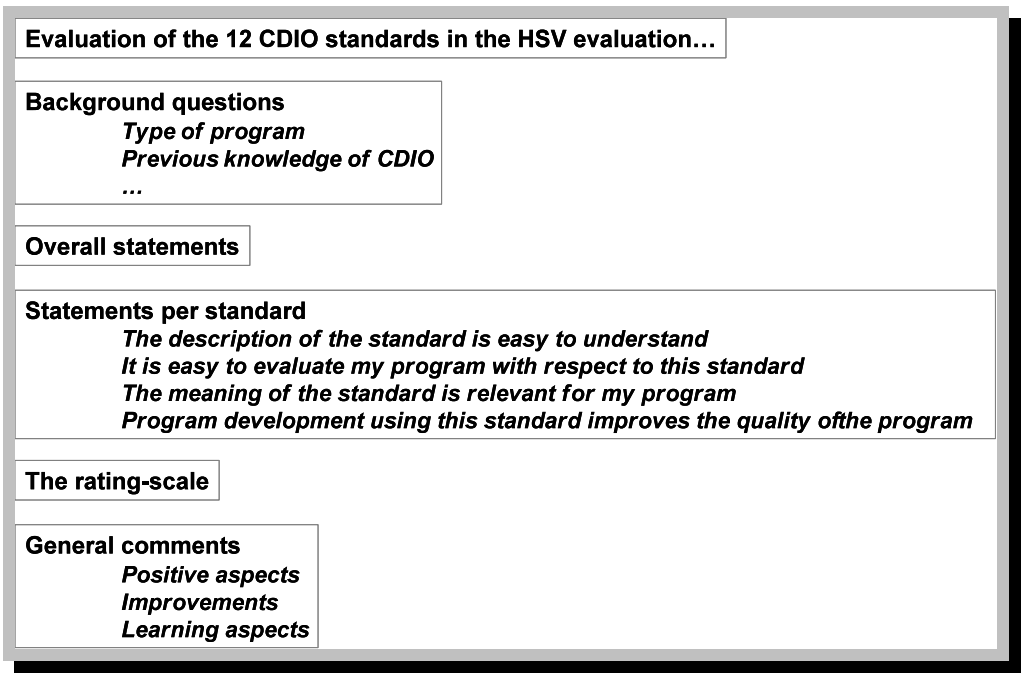

Figure 5: Structure of survey questionnaire.
The overall statements are given in Figure 6 when presenting the results.

RESULTS

The figures 6-7 and 9-10 below show some statistical results from the survey. The results are organized per statement, and the mean value and standard deviation for each statement of standard are illustrated graphically. In some rare cases the respondents did not give a complete answer, but there are roughly 30 observations for each kind of statement and standard. For all statements and standards the standard deviations are rather high. One reason is a small number of highly critical respondents giving "Completely disagree" for all statements, also for those that were not CDIO-specific but rather related to good educational practice in general. After discussion it was decided not to exclude those data from the analysis. Due to the relatively small data set those responses will have a substantial influence on the standard deviation.

Overall questions

The second part of the survey contained 12 overall statements related to the entire set of CDIO standards. For each statement the respondents were asked to answer using a scale ranging from 1 to 5. Level 1 corresponds to "Completely disagree", and level 5 corresponds to "Fully agree". The results for the overall questions are given in Figure 6. The overall average rating is just above 3. The highest rating is obtained for standards 10 “Program development guided by the standards improve the quality of the program” and 12 “Evaluation does not require help from an expert”, respectively. Three statements fall somewhat below the average. These are statement 3 “It is easy to make a program evaluation with the standards and the rating scale”, statement 6 “The standards simplify communication between different stakeholders in program development” and statement 11 “The evaluation results are easy to interpret”.

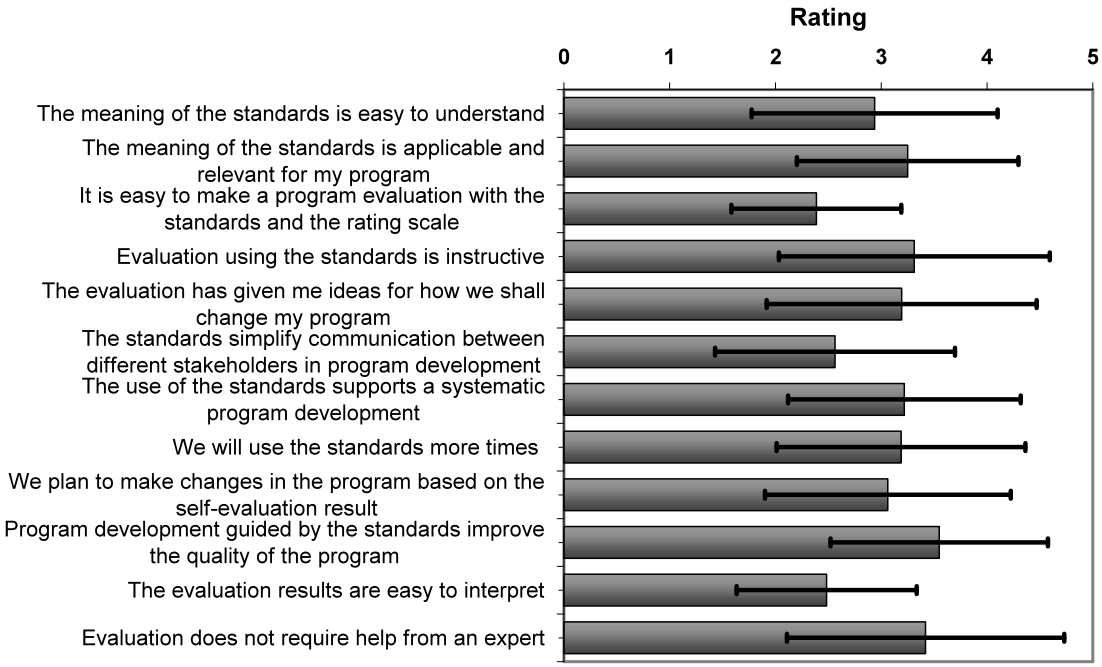

Figure 6: Average rating of the overall statements.
The error bars indicate the standard deviation.

Questions per standard

Four statements were made for each standard, and the respondents were asked to answer using a scale ranging from 1 to 5. Level 1 corresponds to "Completely disagree", and level 5 corresponds to "Fully agree". The English translation of the statements read:

- The description of the standard is easy to understand.
- It is easy to evaluate my program with respect to this standard.
- The meaning of the standard is relevant for my program.
- Program development using this standard improves the quality of the program.

Ease to understand

The first statement concerns the ease to understand the description of the principle. Figure 7 shows that the mean values are fairly high, and that standard 1 caused most problems. This observation is further discussed in the section below. The mean value of standard 12 is also somewhat lower. This may be connected to the difficulty in understanding standard 1, since standard 12 says that the program shall be evaluated with respect to standard 1. The mean values for standard 7 and 8 are slightly lower than the surrounding values. This can be related to difficulties with interpreting topics like “experiential learning” and “active learning”.

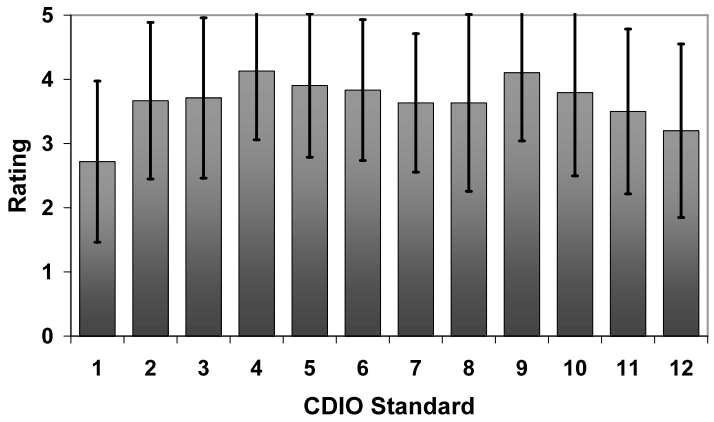

Figure 7: Average rating of the ease to understand each of the 12 CDIO standards. The error bars indicate the standard deviation.

In order to illustrate the scatter among the respondents for the ease to understand standard 1, the number of respondents for each rating is summarized in Figure 8. This figure clearly illustrates the difficulties for many of the respondents to understand standard 1.

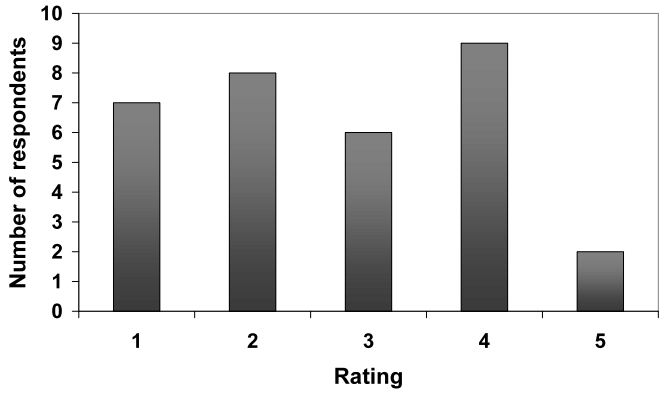

Figure 8: Rating of the ease to understand CDIO standard 1 for all respondents.

Program evaluation

The second statement deals with how easy it is to make program evaluation based on the CDIO Standards, and the statistics for the answers are depicted in Figure 9. Also here the mean value for standard 1 is lower than for the other standards. It can also be seen in the figure that the mean level over all 12 standards is lower for this statement compared to the first one.

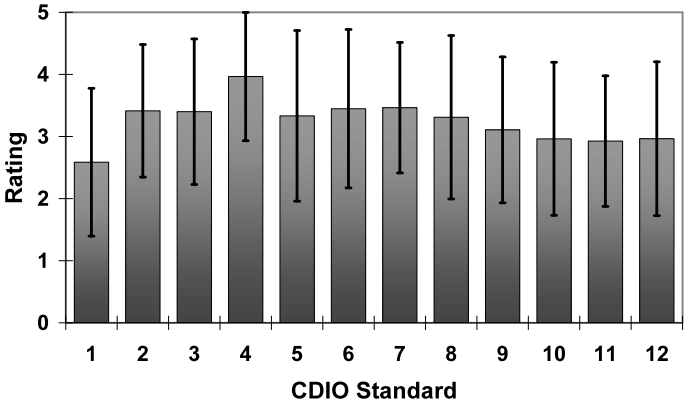

Figure 9: Average rating of the ease if making program evaluation with respect to the 12 CDIO standards. The error bars indicate the standard deviation.

Relevance

The judgement of the relevance of the CDIO Standards for the program is shown in Figure 10. Except for the slightly lower value for standard 1 the mean values are all between 3.5 and 4.0.

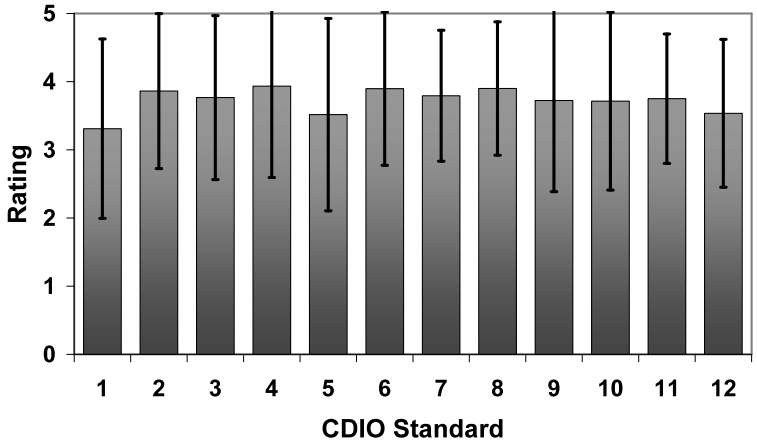

Figure 10: Average rating of the relevance of each of the 12 CDIO standards. The error bars indicate the standard deviation.

Program improvements

The fourth statement deals with use of the CDIO Standards for program improvement and the results of the rating can be seen in Figure 11.

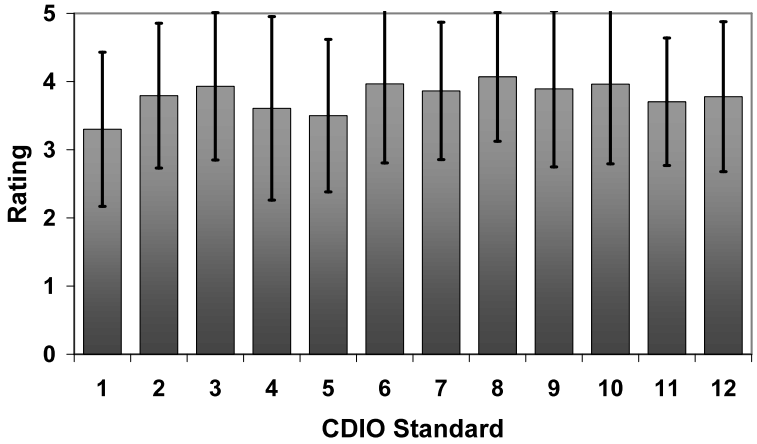

Figure 11: Average rating of benefits for program improvement of each of the 12 CDIO standards. The error bars indicate the standard deviation.

The rating scale

The questionnaire also contained two statements concerning the rating scale used when evaluating a program with the CDIO Standards. See Figure 2. The statements read:

- The rating scale has an adequate number of levels.
- It is easy to understand which value to select.

The mean values for the two statements are 3.6 and 2.5 respectively. This indicates that several respondents had difficulties evaluating the program using the existing rating scale. This is also illustrated in the discussion section below.

DISCUSSION

The survey revealed a number of issues of general interest. Careful consideration of some of these issues will help in future use of the CDIO Standards. We will here present some of these issues as a list of observations, and we will at this stage not consider putting priorities on them. The observations are grouped under the headings relevance and applicability, benefits, understandability and limitations.

Relevance and applicability

The data from the survey indicate clearly that the CDIO standards state a number of principles that are relevant for many types of engineering programs. However, the survey also shows that that especially standard one, i.e. CDIO as a context, caused problems concerning interpretation and relevance. There is a background in that there has been no prior explicit attempt to define the role of an engineer in the engineering education framework in Sweden. In addition, as mentioned above, there are approximately 100 engineering programs in Sweden, and they represent a broad spectrum of disciplines and ideas. It should be pointed out that the modifications to the original CDIO standards made in the HSV version included a provision for programs to re-redefine standard one into one that would be better fitted to the programs particular context. It should be further noted that if a program chose this option, the remainder of the standards would still keep their essential meaning, only slightly modified to fit into the alternative context.

Some Swedish engineering programs have a very strong engineering identity, and essentially sympathized with standard one. However, some of these programs also indicated initial difficulties in translating standard one into their context prior to accepting it. "*The major discussion was about the context. Is this the context, is it only this and nothing more?"* (interview). In some cases this resulted in variants on standard one which were close in content to the original one but more explicitly linked to a particular industry *"The principle is to educate engineers to meet the needs of the construction industry, ie for planning, design, engineering, production, operations and maintenance"*. Another program that educates engineering teachers rather than engineers chose to state their context as "*The didactical process: Analysis of educational needs, planning, implementation, assessment, evaluation and development."* Also this statement has basic similarities within the original statement but is more explicitly linked to their students' future role as teachers.

Other Swedish engineering programs formally lead to an engineering degree but are strongly science-oriented, e.g. in physics or biology. It was not easy for some of the latter programs to identify with the image of engineering that is reflected in the standards: *"[The standards] seem to be made thinking of mechanical engineering, electrical engineering, but probably not so much considering the natural science part of the engineering domain."* One such re-defined standard one read "*The X program is strongly research-oriented and the students learn how to think, analyze, and solve problem in a research context rather than in the technical production context. The emphasis is more on knowledge production than on "product" production*".

Understandability

Out of the four questions asked for each standard, the one that evaluates the ease if making a program evaluation with respect to the CDIO standards is the one with the lowest average score (3.24 of 5). This also evident from the responses to questions related to the whole set of standards (Figure 6). The difficulties appear to come from two main sources: interpreting standard one as discussed above and the rating scale. Especially the rating scale caused trouble for many respondents: The rating scale has two components: planning and implementation. Some respondents thus report that it is difficult to choose the "right" value for a particular standard.

Moreover, the rating scale is designed to give a premium on planning and documentation in order to create a solid base for the systematic development and discussion of program plans. This is a key point in the CDIO model. However, some respondents argue that a good plan is no guarantee for a good implementation, and that there may be good implementations without explicit plans or documentation. In this sense, they seem to feel that they get a lower rating than they deserve. *"There was great importance attached to writing things down. In the long run that is reasonable. But you can*

have a system although it is not documented, and you can have routines, even though they are unwritten."

Some respondents also voice concerns over the meaning of concepts such as "personal and interpersonal skills", "product and system development", and "experiential learning", and request definitions or specific examples: *"Formulate this better. Write so a child would understand what is meant."*

Benefits

When asked about what was positive about the standards, it is clear that the focus on systematic planning and documentation is perceived as new and useful. Managing the program guided by the standards is seen as superior compared to other "management" techniques that are hinted at, such as depending on chance or fighting fires: *"The most obvious advantage is that the standards are systematic and good! You get an explicit structure for the work; you can get a basis for decision and renewal. And when you have decided that this is what we mean by engineering education, you can manage much more clearly."* (interview). *"The most obvious advantage is - without doubt - the holistic assessment. This is evidently a management tool. It gives a general impression of the programme, and whether there is a systematic approach or if it is just… a matter of chance what happens."* (interview)

Within the framework of a systematic approach the respondents' further point to specific aspects that are supported, such as the advantage of having a clear set of guidelines to support decisions and follow-up. *"The standards support decision-making because there is always discussion when you want to develop and change things. If we can agree that it is desirable for the program to address this, you can conclude that this must then be changed or removed; we must do it this way. Then you don't change things so randomly, but the structure is very clear. It gives us clear reasons why we want certain courses to change, what it is that we want to achieve."* (interview). This is underlined by the data from the survey which strongly supports the notion that program changes made according to the CDIO would improve program quality (figure 6, statement 10).

The format of the self-evaluation where the rating of each standard is backed with evidence and needs for actions are identified is described as giving a good agenda for implementing and following up on the change process. *"We would have found out a lot of this [on our own], but [using the standards] made it more explicit, more specific. It was also a help to actually analyse what measures to take, an action plan where the measures are related to what we want to achieve, related to these standards and our assessment of fulfilment."* (interview) *"What I learned was to structure [program development] and divide it into parts that can actually be tackled practically. It is a clear help to divide this into manageable processes. Then I can prioritize down some of the processes because other parts are more important right now. And I can leave some things, like competence development, to other actors. But then that becomes explicit in a different way, which is positive."* (interview)

Other benefits mentioned include that the standards highlight the professional role of an engineer and promote integrated learning.

Limitations

Whilst the CDIO standards gives a framework for capturing the domain-independent, "generic", competencies expected from future engineers, the idea is also that the development of such skills goes hand-in-hand with the development of disciplinary knowledge. However, many respondents indicate concerns with the perceived focus on personal, interpersonal and product and system development and deployment skills. Their impression seems to be that the considerations of disciplinary knowledge and the connection to research are weak. The respondents indicated that they felt that disciplinary strengths, and research perspective, should be appreciated in the evaluation, rather than taken for granted. Especially if one of the purposes of the evaluation is to compare programs from different universities, the respondents from universities with strong research environments wanted the evaluation to reflect also their traditional strengths. *"[The standards] capture a certain aspect of a program …; what you need in addition to [disciplinary knowledge] to be a good engineer. I think the standards focus on this addition, that's how I perceive them. But it is taken for granted that you have well functioning disciplinary activities. But that is not the case in all programs." (interview).* There

were, however, also respondents who could see good reasons for this focus: *"The connection to research is hardly mentioned, and that feels a bit distorted. But at the same time [the standards reflect] things that we are traditionally bad at. It is a good way to focus on that. Because as program chairman it is your job to always say: "think about the overall picture", "what are they going to work with and what knowledge do they need". But you don't have to nag them about disciplinary knowledge. That comes automatically because they are faculty's own interest. First and foremost they think about the disciplinary content. It is already in place, but all the other things are not as evidently there." (interview)"*. This points to the need to complement the CDIO standards with other instruments in an overall evaluation, and to make its role in the context clear.

Many respondents emphasize the need to view the evaluation exercise as a support for quality enhancement processes, rather than quality assurance. The scale is not considered useful for rating a program in absolute terms, and compare ratings. *"I very much approve of using a quantitative model for the evaluation. It is not so much about whether it actually is a "3" or a "2", but it is about having to think about it. If you rate yourself higher next time that means something must have happened. Then you must reflect on how to motivate it." (interview)* "*The most obvious disadvantage is if we start making comparisons with these numbers, and say that 27 is worse than 32. I'd like to see this as a development tool, rather than a ranking system." (interview)*

There are some topics in the Standards where the outcomes of a program evaluation to a large extent depend on the organization and structure of the university. The most important topic of the kind is the competence of the faculty, as discussed in Standards 9 and 10. At several universities the engineering programs are managed by cross-departmental program boards (or similar), while a faculty member belong to a particular department. Using the self-evaluation data as evidence, the program can exert influence also on the departments and higher levels of the university, but it may still be a tough challenge for a program to have a real impact on faculty recruitment and competence development, and other issues that are owned by the departments.

CONCLUSIONS

In the Swedish national evaluation of engineering degree programs a modified version of the CDIO standards has been used to evaluate about 100 engineering programs. Survey and interview results indicate that the standards are relevant and applicable for a wider range of programs than have earlier used the standards, and, that making changing towards implementing the standards would improve program quality. The survey results also indicate that the standards most important benefit is that they provide a basis for systematic program development. Challenging issues when doing a CDIO standards-based self-evaluation include interpreting standard one in the context of the science and technological domain in question and the proper use of the rating scale. There are also concerns that the fact that mainly the program's actions to develop personal, interpersonal and product and system development and deployment skills are visible in the evaluation does not do justice to its attention to disciplinary skills and connections to research. This points to the need to complement the CDIO standards with other instruments in an overall evaluation, and to make its role in the context clear.

ACKNOWLEDGEMENTS

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