A SURVEY OF CDIO IMPLEMENTATION GLOBALLY – EFFECTS ON EDUCATIONAL QUALITY

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ABSTRACT

The CDIO approach to engineering education was introduced in the early 2000's. Some universities have gained considerable long-term experience in applying the approach, and consequently it seems timely to summarize and evaluate those experiences. This paper thus reports the results of a survey distributed to all members of the CDIO Initiative in October 2014.

The aims of the survey were to:

- Map out where and in what programs/disciplines CDIO is currently applied
- Evaluate the effects on outcomes, the perceived benefits, the limitations, any barriers to implementation, and ascertain future development needs

Forty-seven universities from twenty-two countries participated in the survey. The main findings from the survey include the following:

- The most common engineering disciplines in which CDIO is implemented are Mechanical, Electrical, and Computer Engineering. However, many CDIO schools have also implemented CDIO in Industrial, Civil and Chemical Engineering.
- The main motives for choosing to adapt CDIO are; ambitions to make engineering education more authentic; the need for a systematic methodology for educational design; and the desire to include more design and innovation in curricula.
- Most CDIO implementations successfully achieve both goals for learning and for external recognition of educational quality.

KEYWORDS

CDIO implementation, Survey, Success factors, CDIO Standards 1-12

INTRODUCTION

The Conceive-Design-implement-Operate (CDIO) approach (Crawley et al., 2014) to engineering education was introduced in the early 2000's. The goals of CDIO include educating graduates with a deep and working knowledge of engineering fundamentals, who can lead in the development and operation of complex technical systems, and who have a strategic understanding of the role and impact of technology in society. The goals should be achieved within the constraints of fixed resources in terms of student and faculty time, the size of student workspaces, and budgetary restraints. CDIO proposes that an educational design that meets these goals is characterized by learning outcomes established in close contact with stakeholders, by design-implement experiences, and by integrating learning of the discipline with the development of professional skills. CDIO further features a systematic approach for designing and continuously improving education. The CDIO approach is formalized in the CDIO framework, consisting of the CDIO syllabus and the CDIO standards.

The large number of universities worldwide that have adapted the CDIO approach is a sign that the CDIO approach has promise and seems plausible to many. However, there are certainly valid questions to ask: What is the evidence that adaptation of CDIO leads to improved student learning? Will the changes to engineering education suggested by CDIO result in gains in certain knowledge and skills areas but reductions in other areas, such as mathematics and science? How resource-demanding is CDIO in comparison to the status-quo approach to engineering education? How successful are universities in achieving the goals of CDIO? What needs to be considered in order to successfully implement CDIO?

The overall purpose of this paper is to investigate these issues. We are taking advantage of the circumstance that a large number of universities have implemented CDIO to enable a quantitative and survey-based research design. We are further examining the different levels of CDIO experiences amongst CDIO Initiative members to explore the progress of CDIO implementation. Questions pertaining to implementation include: How long does it take to implement CDIO? Which areas are challenging or easy in order to implement CDIO? This paper thus reports the results of a survey conducted in October 2014 with all members of the CDIO Initiative, which currently stands at more than 120 universities from around the world.

Specifically, the aims of the paper are to:

- Map out where and in what programs/disciplines CDIO is currently applied;
- Evaluate the effects on outcomes, the perceived benefits, the limitations, and any barriers to implementation; and
- Ascertain future development needs.

The remainder of the paper is structured as follows. We first review earlier work that has aimed to categorize and follow up on CDIO implementation efforts, focusing on the university and program level. We then account for the design of the survey. A presentation and discussion of the findings follow. Finally, conclusions are listed.

EARLIER WORK

Gray (2008) conducted a CDIO status survey, in which 23 of the then 27 members of the CDIO Initiative participated. Gray's survey focused on the use of the CDIO standards as a quality enhancement tool and on the progress of CDIO member universities with respect to the standards. The CDIO members were categorized as "new" (≤ 2 years CDIO experience), "intermediate" (3-4 years experience) and "senior" (≥ 5 years experience). Gray's survey showed that for new CDIO members, Standard 5 (Design-implement experiences) was rated highest, while Standard 9 (Faculty Professional Skills) and Standard 12 (Program Evaluation) were rated lowest. Amongst the senior CDIO members, CDIO standards 1, 2, 4, 5 and 12 were rated highest and standards 9 and 10 lowest. Gray's data suggested that many schools had joined CDIO with an already existing interest and experiences in design-implement, but also that the standards related to faculty competence (9, 10) are the most difficult to improve on.

A number of CDIO programs have enough experience of CDIO to be able to evaluate long-term effects of CDIO implementation:

An early study was conducted at Linköping University comparing student cohorts who had started their studies before the CDIO introduction with students that had followed a CDIO program from the start. They found that the CDIO students considered themselves as significantly better at teamwork, and that they valued the CDIO courses/project as the most valuable learning experience during their studies. The Linköping students specifically identified the skills of problem solving, of critical thinking, of handling heavy workloads, and of project management as the most transferable to professional work situations (Edvardsson Stiwne & Jungert, 2007). However, they were not able to discern any difference between pre-CDIO and CDIO graduates concerning employability (high already before) and student retention (still low) and student recruitment (continued to drop).

Malmqvist et al. (2010) presented a ten-year follow up of Chalmers' CDIO implementation in mechanical engineering. Chalmers alumni survey data shows that mechanical engineering graduates self-assess their design, communication and teamwork skills significantly higher than graduates from other programs at Chalmers. The mechanical engineering program at Chalmers has won several national (Sweden) awards for high quality education. The paper further shows that the CDIO implementation required substantial investment costs, but that the operating costs for the education are manageable.

Evaluations of the chemical engineering program at Singapore Polytechnic (Cheah *et al.* (2013); Ng (2014)) have identified positive effects related to student retention and alumni self-assessment of communications, systems thinking and creative skills. However, the same studies also found it hard to assess conclusively effects on graduate employment rate, salary and course satisfaction ratings.

ISEP Porto (Martins et al., 2013) reported that the CDIO implementation of its computer engineering program had lead to a national (Portugal) ranking as a leading computer engineering program, and improved student retention, employer satisfaction and quality of final degree projects.

Duy Tan University (Nguyen et al., 2014) describe how CDIO was used for the successful ABET accreditation of their programs. CDIO is said to have helped identify weaknesses with regards to ABET criteria, and it is argued that CDIO is the best tool for ABET accreditation preparation.

In conclusion, the demographics and progress of CDIO implementations have not been surveyed since 2008. Since then, the CDIO Initiative has grown from 27 to 118 members. Effects, barriers and success factors of/for CDIO implementation have so far, to our knowledge, only been surveyed by individual programs. These program-specific evaluations identify typical benefits of CDIO, but also some intended goals that are more difficult to conclude on. The work reported here aims address to this gap, by investigating if reported benefits and success factors are valid across a larger sample of implementations.

SURVEY DESIGN

The survey was comprised of approximately 50 questions in the following categories:

- University categorization and CDIO use;
- Level of a university's CDIO implementation;
- Statements about the effects on input, resource and output metrics;
- Barriers and success factors; and
- Open-ended questions.

The university categorization questions considered basic university demographics such as size, location, QS ranking, and faculty-to-student ratio.

The state of the university's CDIO implementation section included questions on the disciplines to which CDIO was applied, motives for joining CDIO, CDIO-like experience prior to joining the CDIO Initiative, and participation in CDIO Initiative activities. In this section, the respondents were asked to complete a self-evaluation regarding CDIO standards at the initial state of implementation (defined as when the university joined the CDIO Initiative) and the current state.

The third section of the survey aimed to map out the effects of the CDIO implementation on metrics for educational input/output, learning and support processes, and control and resource elements. A number of statements were presented for the respondents, who were asked to rate their agreement with the statement on a 1-10 scale, ranging from "totally disagree" (1) to "totally agree" (10).

The fourth section had a similar design to the third, but with statements related to barriers and success factors for CDIO implementation.

The final section of the survey comprised free-text response questions regarding customizations of the CDIO framework, on development needs for the CDIO framework, and for the CDIO Initiative.

The survey was sent to the CDIO school representatives, "CDIO leaders", one person at each member institution. The CDIO leaders were recommended to form a small team of faculty from their institution to discuss the questions and their answers before responding.

FINDINGS

The survey was distributed to 119 potential respondents. 47 responses (39.5%) from 46 universities were received. One university submitted two responses that related to two different programs. The responses were from 22 countries and from 7 CDIO regions.

Demographics of participating institutions

The majority of the institutions that participated in the survey reported having 15,000 or more students, as noted in Figure 1. Teaching resources are presented in Figure 2, with the largest percentage of institutions having between 2 to 5 graduating students (Bachelor's or Bachelor's + Master's) each year per full-time equivalent (FTE) faculty member. Research intensity is presented in Figure 3 where almost 40 % of the institutions reported having between 1 and 4 graduate students per faculty member. An equal percentage of institutions reported having 1 or fewer graduate students per FTE.

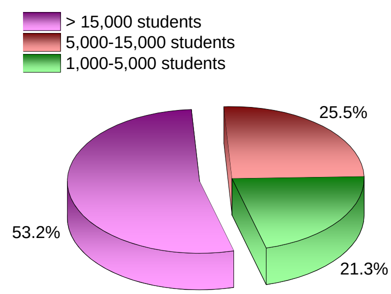

Figure 1: Size of Institutions Participating in Survey

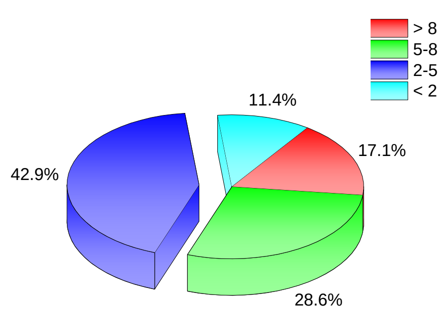

Figure 2: Teaching Resources -
Undergraduate Degrees Awarded / Full-Time Equivalent (FTE) Faculty

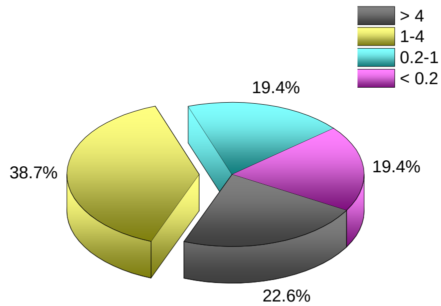

Figure 3: Research Intensity - Graduate Students / Full-Time Equivalent (FTE) Faculty

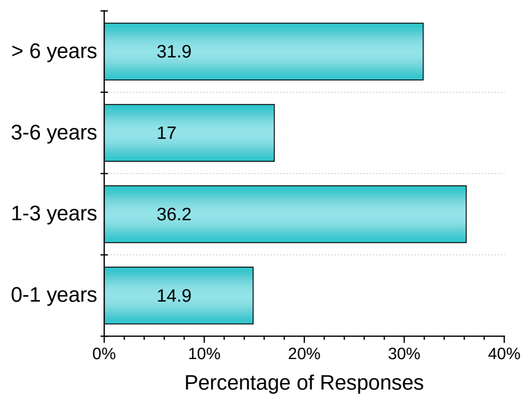

Figure 4: For how long have you applied CDIO?

Of the universities completing the survey, the majority have been involved with the CDIO Initiative for 1 to 3 years, as shown in Figure 4. The second largest cluster is for institutions with more than 6 years of experience. This is reflective of the distribution of institutions within the CDIO Initiative. In 2009, there were 35-40 collaborators, and these were institutions with 6 or more years of experience. Given the 119 collaborators at the time the survey was conducted in 2014, the percentage of institutions involved with 6 or more years of experience would be between 30% and 35%, as reflected by the survey participant results in Figure 4.

Motives for joining CDIO, prior experience and application to what disciplines

The motivating factors for joining CDIO are outlined in Figure 5, with nearly three quarters of the respondents indicating the positive aspects of a systematic approach for education reform and methods for making education more authentic. Approximately one-third reported employer feedback about the lack of certain skills in graduates, and only 10% reported student recruitment, retention, or satisfaction as reasons for applying CDIO. Approximately 60% of the institutions reported having only applied a small number of the concepts of CDIO prior to their programs joining, as shown in Figure 6. Less than 10% reported having already applied the concepts extensively prior to joining.

The disciplines to which CDIO is applied by institutions is shown to the left in Figure 7, with Electrical and Mechanical Engineering programs being the most common, followed by

Computer Science, Industrial, Civil, Chemical, Aeronautics and Aerospace, and Bioengineering. This data is compared to data published (Yoder, 2014) by the American Society of Engineering Education (ASEE) to the right in Figure 7. The ASEE data shows the percentage of North American graduating Bachelor's by discipline. Although the ASEE data considers only North American Engineering programs, it does provide an indication on the relative size of disciplines. With this it is possible to better understand why application of CDIO (Bioengineering, for example) is lower than application to another discipline (Mechanical, for example).

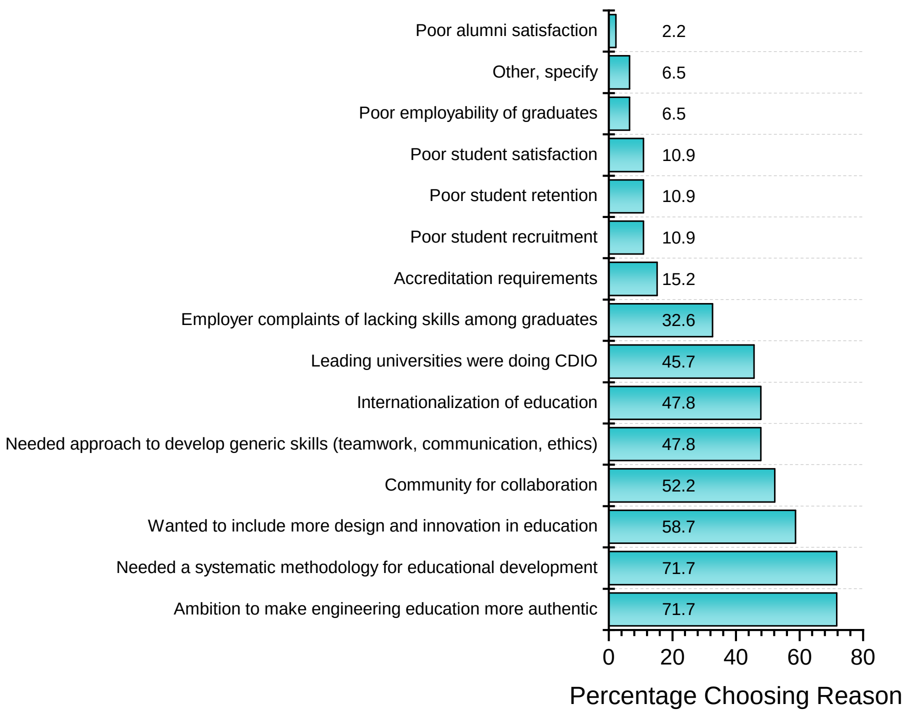

Figure 5: Motivation for Applying CDIO

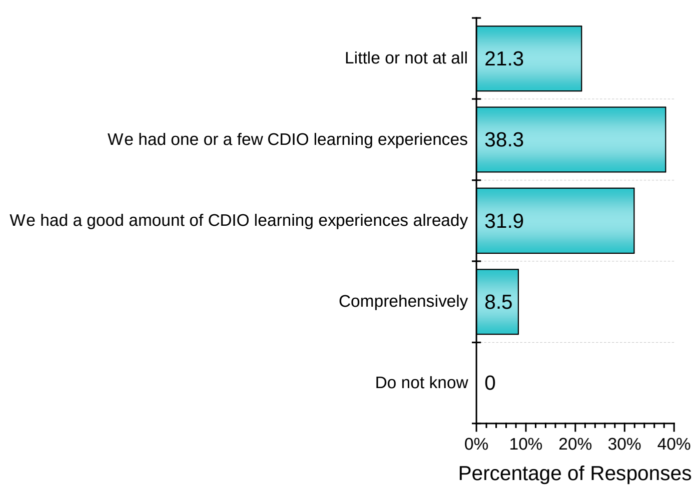

Figure 6: Extent of applying CDIO prior to joining the CDIO Initiative

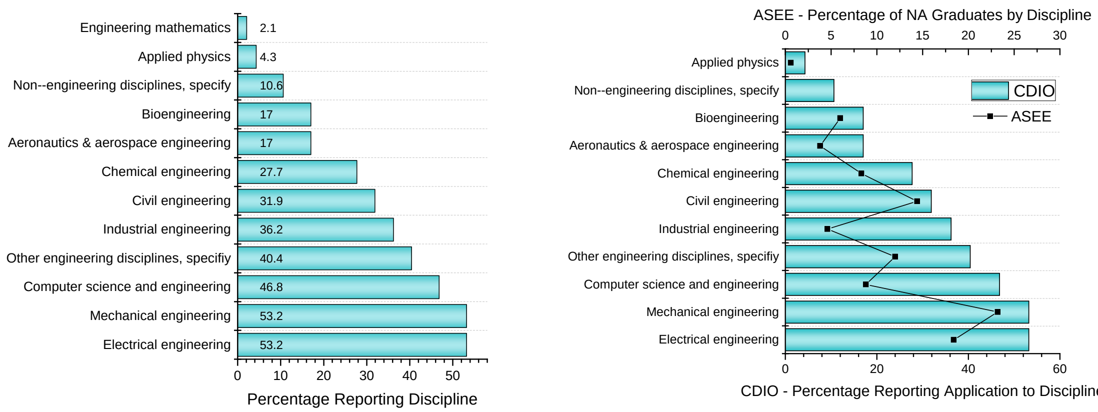

Figure 7: To what disciplines have you applied CDIO?

Progress of CDIO implementation

The data provided in Table 1 provides an indication of how institutions have self-reported their progress on implementation of the twelve CDIO Standards, self-assessing both their Initial and Current state. The data presented in the Table is an average of all reporting institutions, irrespective of the amount of time spent on implementing CDIO.

Figure 8 presents the Table 1 data set, only now segregated based on the number of years since first adopting CDIO. The figure reports the Cumulative Increase, with Increase being defined as the difference between the Current and the Initial self-assessment value for each of the CDIO Standards. The figure reveals that programs continue to move higher on the 0-5-points self-assessment scale for most of the CDIO Standards. One exception is Standard 3 where an uncharacteristic value is reported in the “0-1 years” grouping. Standard 3 refers to Integrated Curriculum, and data for the “0-1 years” category disagrees with what otherwise would be monotonic growth. Examining the survey data, only 7 responses were received in the “0-1 years” grouping for Standard 3, and three of these seven chose “No Response.” Consequently the “0-1 years” data for Standard 3 is viewed as statistically unreliable.

Table 1: Progress of CDIO Standards Implementation

Standard		Initial		Current	
		Average	**Std dev**	**Average**	**Std dev**
1	CDIO Context	1.73	1.14	3.55	0.97
2	CDIO Learning outcomes	1.88	1.26	3.77	0.87
3	Integrated curriculum	1.66	1.19	3.37	1.04
4	Introduction to engineering	1.92	1.42	3.78	1.28
5	Design-implement experiences	2.21	1.51	3.88	1.17
6	Engineering workspaces	1.97	1.18	3.34	0.96
7	Integrated learning experiences	1.74	1.36	3.29	1.11
8	Active learning	1.65	1.07	3.15	0.99
9	Enhancement of faculty engineering competence	1.36	1.19	2.64	1.18
10	Enhancement of faculty teaching competence	1.64	1.11	2.95	0.99
11	CDIO skills learning assessment	1.58	1.16	3.05	0.88
12	Program evaluation	1.23	1.12	2.69	1.26

Other exceptions to growth with time exist for Standard 9 (Enhancement of Faculty Competence) and Standard 10 (Enhancement of Faculty Teaching Competence) where the vertical distance between lines for these Standards do not increase significantly with years of CDIO application. This is further explored in Figure 9 where the Cumulative Increase in Standards 9 and 10 (plotted on the left) reveal modest growth with time while the remaining ten Standards (shown on the right) reveal more substantial growth. Standards 9 and 10 refer to a change in behavior of faculty members, something that is more difficult to influence than Curriculum (Standards 1-5, 7-8), Evaluation (Standards 11-12), or Workspaces (Standard 6). A recent study conducted in the UK (Graham, 2015) reached a similar conclusion. Graham found that despite a growing recognition of the importance of teaching quality by university leaders, faculty are still not convinced that teaching achievements above an acceptable level will be counted in promotion cases. As long as this perception dominates, the likelihood for significant improvement of faculty teaching skills will be low.

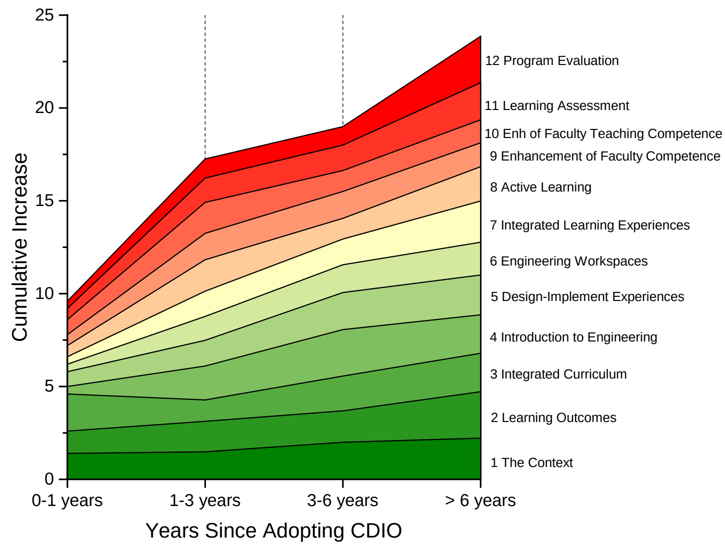

Figure 8: Cumulative Increase in CDIO Standards by Year Since Adoption

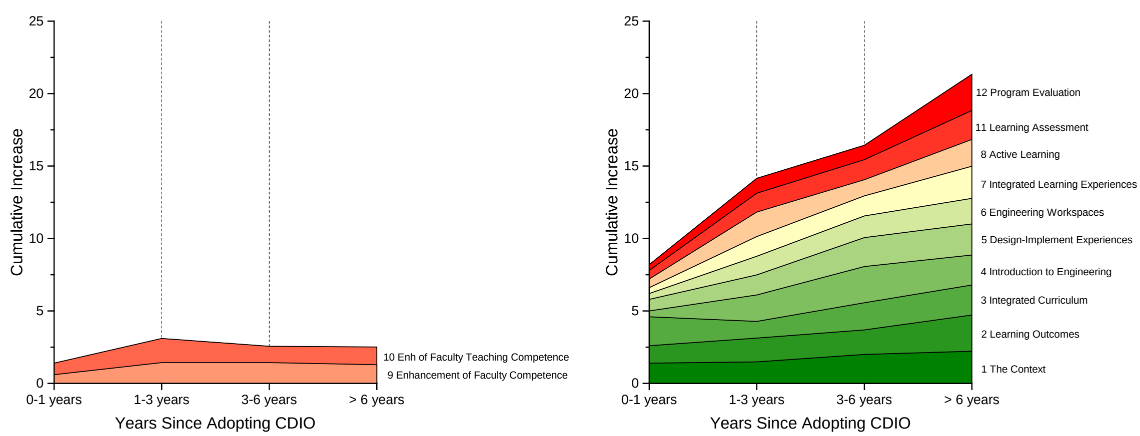

Figure 9: Cumulative Increase in Select CDIO Standards by Year Since Adoption

The average increase by Standard for all programs is shown in Figure 10. The graph shows that the increase (Current State – Initial State) is greatest for Standard 2 (Learning Outcomes) and lowest for Standard 9 (Enhancement of Faculty Competence). In order to determine if the increase was related to the Initial State, a stacked bar graph was also considered, as shown in Figure 11.

Figure 11 shows that Standard 5 (Design-Implement Experiences) is rated highest overall; however, the increase in this Standard is only fifth highest (Figure 10), perhaps due to the fact that the Initial State for Standard 5 was already the largest to begin with, leaving less room for incremental improvement. Despite these differences in relative improvement between standards, however, the survey respondents' universities/program have clearly made significant advancements in all CDIO standards. It also appears that survey respondents have adapted CDIO more as a whole than by cherry-picking specific areas.

These data are similar to Gray's (2008) findings. Gray also found that Standard 5 (Design-Implement Experiences) tended to have the highest rating amongst new universities, and that Standard 2 (Learning Outcomes) had a high increase. However, in Gray's study the highest gain was for Standard 12 (Program evaluation).

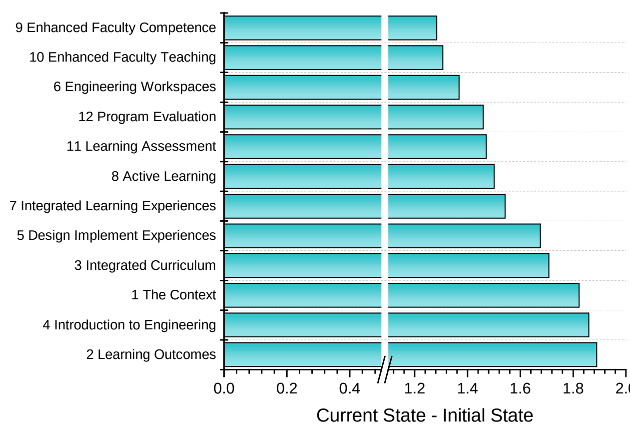

Figure 10: Increase by CDIO Standard

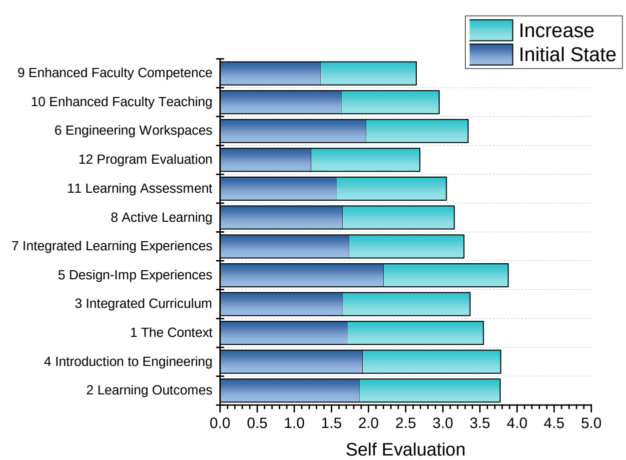

Figure 11: Current State in CDIO Standard = Initial State + Increase
(Largest Increase – Std 2; Smallest Increase – Std 9)

CDIO implementation effects

The survey further aimed to investigate how the survey participants rated the effects that CDIO implementation had with reference to specific statements indicating positive effects on educational quality, such as improved graduate knowledge and skills, improved alumni satisfaction, or graduate employability. A few statements of negative effects such as increased costs and decreased math and science knowledge were also included. The sources for the statements included Crawley et al. (2014) and the EUR-ACE framework standards (ENAEE, 2008). Survey participants were asked to respond to each statement on a ten point scale, ranging from “totally disagree” to “totally agree,” including a provision for “cannot assess.”

Table 2 shows the statements and their ratings. It can be observed that there is very strong agreement for statements related to CDIO’s main goals for learning (improved conceive-design-implement-operate, personal and interpersonal skills). Further, there is also strong agreement for statements related to external recognition (accreditation, government awards) and collaboration with other universities. We note that the statements for which there is strongest agreement are well aligned with the motives for applying CDIO (Figure 5). One respondent commented: *““CDIO gave a framework for our students to develop these skills in a 'structured' manner, and more holistically. Prior to CDIO, student experiences were more skewed towards 'implementing and operating'. Now, with inclusion of design thinking, students develop good conceiving skills as well.”*

Further, there is strong agreement related to student and alumni satisfaction and recognition (course rating, alumni satisfaction and employability “*We have positive signals from employers that we have strengthened our student's employability”*, student awards *“Students are doing better in student competition teams such as FSAE, Mini Baja, Solar Car, Solar Decathlon, Petro Bowl, iGem, etc.”*). However, it can also be noted that relatively many participants replied “cannot assess” to statements related to alumni. It seems that many are lacking a systematic mechanism for surveying their alumni.

Statements with a tendency to neutral agreement include student recruitment, retention and higher pay for graduates. Such goals are often common to education reform efforts (Graham, 2012), including CDIO (Crawley *et al*., 2014), but the effects of CDIO implementation on these areas seem to be minor or difficult to discern. This finding confirms results from Ng’s (2014) follow up of Singapore Polytechnic’s chemical engineering program.

A number of statements expressed possible trade-offs or risks related to CDIO implementation (“CDIO implementation required significant investments in education infrastructure”, “CDIO implementation has led to increased operating costs”, “Graduates have less knowledge of math and science”). These statements have been valued as neutral or weak, i.e. there is little support for these statements amongst the survey participants: “*Our core engineering science and maths is still present to the same degree as it always has been. Contextualizing the work through projects should help to embed and allow students to apply core knowledge.”* However, there is a relatively high spread, indicating that in some cases CDIO has been associated with both significant investments and higher operating costs. Nevertheless, even considering the spread, there seems to be little support for the statement that CDIO implementation had led to less knowledge of mathematics and science.

Table 2: Effects on education input, resources and output

Statement	Avg	Std dev
Strong agreement (average > 6.5)		
Graduates have improved conceive-design-implement-operate skills	7.9	1.8
CDIO implementation has supported accreditation	7.9	1.7
Graduates have improved interpersonal skills	7.8	1.6
We have received recognition for high quality in education (for example awards from government agencies)	7.5	2.1
We have increased collaboration with other universities for educational development	7.5	1.9
Graduates have improved personal skills	7.5	1.6
We have an increased number of published papers on educational development	7.2	2.3
Faculty teaching competence has improved	7.1	1.8
Quality of final degree reports/capstone design projects have improved	7.0	1.9
Alumni satisfaction has increased	6.9	1.7
Course satisfaction ratings have improved	6.9	1.9
Graduate employability has improved	6.6	2.1
Our graduates have received more awards (for example prizes for projects or won student competitions)	6.6	2.4
Neutral agreement (average 3.5 – 6.5)		
Faculty engineering professional competence has improved	6.5	1.8
Student recruitment has improved	6.4	1.9
Student retention has improved	6.3	2.0
CDIO implementation required significant investments in education infrastructure	6.2	2.1
More alumni are starting new companies	5.8	1.6
Graduates entry salaries are higher than for nearby universities who have not implemented CDIO	5.8	1.0
CDIO implementation has led to increased operating costs	5.5	2.5
Weak agreement (average < 3.5)		
Graduates have less knowledge of math and science	3.4	2.2

We can note that some statements have strong agreement on effects, despite typically low amount of increase in terms of CDIO Standards (Figure 10): “CDIO implementation has supported accreditation” is ranked relatively high at 7.9, yet this is the area that shows the fourth least amount of increase in terms of the CDIO Standards, as reflected by Standard 12 – Program Evaluation. We can note that “Faculty teaching competence has improved” is ranked relatively high at 7.1, yet this is the area that shows the second least amount of increase in terms of the CDIO Standards, as reflected by Standard 10 – Enhancement of Faculty Teaching Competence in Figure 10.

“Faculty engineering professional competence has improved” is rated somewhat lower at 6.5, yet this is the CDIO Standard that shows the smallest increase – Standard 9 – Enhancement of Faculty Competence. This can be interpreted as that although it seems difficult to achieve a high self-evaluation rating with respect to these CDIO Standards, even moderate increases may still have noticeable positive effects on education quality.

Table 3: Barriers and success factors for CDIO implementation

Statement	Avg	Std dev
Strong agreement (average > 6.5)		
CDIO is well aligned with the vision and strategy of our department/university	8.9	1.5
University management strongly supported our CDIO implementation	8.1	2.0
The CDIO implementation was associated with higher ambitions for our education	8.1	1.5
We had clear visions and goals for what we wanted to achieve by the CDIO implementation	7.9	1.6
It was easy to customize the CDIO framework to fit our local context	7.3	2.2
If the main CDIO proponent at your university was to retire tomorrow, the changes that have been made to date would remain five years from now	7.2	2.1
CDIO has created attention for education in our university	7.2	2.3
We had sufficient financial resources to implement CDIO	6.6	2.4
Neutral agreement (average 3.5 – 6.5)		
Faculty were incentivized and recognized for CDIO implementation efforts	5.8	2.5
We measured the impact of our CDIO implementation with suitable indicators	5.7	2.1
Faculty teaching competence was a barrier to CDIO implementation	5.2	2.1
Faculty were resistant to CDIO	4.9	1.9
Faculty engineering professional competence was a barrier to CDIO implementation	4.9	2.4
Weak agreement (average < 3.5)		
None	-	-

Barriers and success factors for CDIO implementation

One part of the survey aimed to investigate how the survey participants rated the importance of published success factors and barriers for sustainable education reform, in context of their CDIO implementation effort. The sources for the statements included Crawley et al. (2014), Graham (2012) and Malmqvist et al. (2010).

Table 3 shows the statements and their ratings. It is evident that the survey participants' CDIO projects generally fit well with university visions and strategies, had strong support from management, had clear goals and visions and were associated with higher ambitions for their education.

Table 3 suggests that these higher ambitions would tend to be related to specific goals for learning (CDIO skills, interpersonal skills) and/or external recognition (accreditation, government awards). All these statements have a very strong agreement and relatively low spread.

The responses further show that the CDIO framework can be purposefully adapted to local contexts, are embodied by more than single individuals and create attention for education at universities. However, the spread of the responses indicate a higher fraction of neutral agreements with these statements.

The sufficiency of financial resources is rated just above the border to neutral agreement and with a relatively higher spread. The respondents free-text comments range from *"No extra resources allocated" to "We have special funds for CDIO"* or *"… Significant external funding for CDIO."* It is apparent that the available financial resources have varied significantly.

However, even schools with low or no additional funding report positive effects of CDIO implementation.

Finally, it can be noted that statements related to faculty resistance and competence were neutrally rated and thus not experienced as strong barriers to the CDIO reform.

Development needs for the CDIO Framework

A free response question asked "*What development or change needs do you see for the CDIO framework*". The answers can roughly be grouped into three categories: renewal of the CDIO vision, specific revisions of the CDIO framework and CDIO implementation guidelines.

Renewal of the CDIO vision. The vision for a CDIO-based education (Crawley et al., 2014) proposes that an engineering education should stress the fundamentals while set in the context of conceiving-design-implement-operation. Further, that salient features include stakeholder-based program goals, an integrated approach to learning disciplinary knowledge and professional skills, and a multitude of design-implement learning experiences. However, one respondent argued that CDIO could be more active in disseminating novel ideas and concepts, such as on-line education, virtual and remote labs. Another respondent suggested that CDIO "*should develop a clear vision on what knowledge and skills the engineer of the future (2030) will need. What are the main differences from the engineer of today? How can the CDIO framework be adapted in order to meet these new demands*?"

Specific revisions of the CDIO framework. Suggestions in this category include revisions of the rubrics for CDIO standards, self-evaluation, stronger attention to internal motivation as a key factor for learning and for successful practice, and explicit consideration of gender and sexual diversity. It was also proposed to develop and specify CDIO framework components for Master and PhD programs.

CDIO implementation guidelines. A number of respondents requested guidelines or instructions for CDIO implementation, including "*how to gather evidence of effects at different levels*", "*a step-by-step how-to-implement book*", "*more guidance of teaching professional skills*". It seems that the implementation advice that is available on the CDIO website is either not fully adequate or too difficult to access.

Development needs for the CDIO Initiative

A free response question asked "*What development or change needs do you see for the CDIO Initiative?*". The answers can roughly be grouped into internal collaboration and external collaboration.

Internal collaboration. Many respondents expressed an interest in expanding collaborative mechanisms such as student and faculty mobility and joint student projects. Some respondents further suggested activities targeted at different CDIO experience levels (novice, intermediate, experienced): *"enhanced focus on outcomes for experienced members", "it would be nice to provide certification of compliance with the CDIO standards", "differentiate between probationary and proper CDIO members".*

External collaboration. A few respondents suggested that the CDIO Initiative should increase its external collaboration efforts, including liaising more closely with other professional engineering education associations such as ASEE, CEEA, and SEFI, and with national and regional university management networks. An international journal of CDIO was also proposed.

Finally, one respondent pointed out the potential tension between scholarship and practice in engineering education development, arguing that the CDIO community should lean towards the latter: *“I would like to see the organization shift into more of a sharing and how-to mode. Focus on practice of engineering rather than scholarship”.*

CONCLUSIONS

The CDIO status survey aimed to investigate the use of CDIO, its progress, benefits and barriers/success factors for implementation. About 40 % of the CDIO Initiative members participated in the survey.

The disciplines in which CDIO is most commonly applied are mechanical, electrical and computer engineering. However, many CDIO members also report CDIO applications in industrial, civil and chemical engineering. The participants also listed a large number of other engineering disciplines in which CDIO had been applied.

The most common motives for applying CDIO were ambitions to make engineering education more authentic, needs for a systematic methodology for educational development, wishes to include more design and innovation in the education and to find an international community to support education knowledge sharing and collaboration.

The survey results show that the participant universities are successfully improving graduate conceive-design-implement-operate, personal, and interpersonal skills. The participants further confirm that they have obtained external recognition for educational quality and established collaboration with other universities. The participant’s responses provide little support for statements related to negative effects on learning or on resource consumption for education. Intended CDIO implementation effects also include improved student recruitment, retention and graduate salaries. However, the survey shows a neutral agreement with these statements.

CDIO implementations viewed as university development projects seem to be strongly supported by university management, aligning well with university visions and strategies, and being sufficiently funded. The survey was not distributed to individual faculty members; hence individual faculty members’ views on CDIO are not studied. However, it can be concluded that the university leaders that responded did not experience (the potential) faculty resistance as a barrier to successful implementation.

Identified development needs for the CDIO framework include a renewal of the educational vision considering the needs of 2030 and the opportunities of digital education tools, revisions of certain CDIO standards rubrics and more specific implementation guidelines.

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