A PROPOSAL FOR INTRODUCING OPTIONAL CDIO STANDARDS

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ABSTRACT

The first version of the CDIO standards was presented in 2005 (Brodeur & Crawley, 2005). The aim of this paper is to explore if meeting current CDIO standards still corresponds to the expectations placed on graduates from leading engineering programs worldwide. In the paper, we first identify engineering competencies that are claimed to be essential both today and in the future, focusing on competencies whose relative importance have grown since the early 2000's. We also identify pedagogical practices that aim to develop these particular competences. We then propose that these emerging skills and best practices should be incorporated in CDIO as "optional" CDIO standards. Whereas the original or "basic" CDIO standards are scoped with the expectations of a bachelor program in mind, an "optional" CDIO standard indicates a more advanced or broadened competence. A set of potential optional CDIO standards is enumerated. Seven of the potential optional CDIO standards are then elaborated in the same format as the current standards, i.e., with a description, rationale and suggested evidence.

KEYWORDS

CDIO Standards, Standards 1-12

INTRODUCTION

The CDIO standards are a key part of the CDIO framework by defining the distinguishing features of a CDIO program, by serving as guidelines for educational reform, and by providing a tool for continuous improvement (Crawley *et al.,* 2014).

The CDIO standards were initially presented in 2005 (Brodeur & Crawley, 2005) and described more fully by Crawley *et a*l. (2007). Rubrics for evaluating programs according to the standards were introduced in 2010. The CDIO standards have since been updated to version 2.0 (Crawley *et al.*, 2014) and the rubrics have been further modified (Bennedsen *et al.*, 2016). These modifications have been relatively minor and have not changed the scope or the main contents of the standards.

While the CDIO standards have been stable during this time period the external context of engineering education has evolved. It is generally recognized that there is increasing need for engineering graduates with competencies in sustainable development, innovation and entrepreneurship, internationalization, multidisciplinary and sociotechnical problem-solving, and digitalization, to mention only a few emerging needed skills. Moreover, recent pedagogical development work conducted within the engineering community was not considered in the original CDIO standards. Further, the CDIO standards are based on the premise of a single-cycle engineering bachelor degree, not a two-cycle bachelor+master degree. There is need to revisit the CDIO standards to evaluate if they are still valid as a benchmark for an internationally leading engineering program.

In this paper, we

- Review the recent literature on needed capabilities of future engineers and on emerging pedagogical approaches that develop these capabilities;
- Propose a structure that supports a controlled expansion of the CDIO standards, in consideration of the pedagogical developments within and beyond the CDIO community;
- Propose a set of requirements for an optional CDIO standard, including that a new standard should reflect the main characteristics of a CDIO program, that it should be generally applicable, i.e. not discipline specific and that it should be evident in a substantial number of CDIO programs as a distinguishing feature;
- Identify and elaborate a set of potential additional, “optional” CDIO standards.

The ultimate aim of the paper is to propose a draft version of the CDIO standards version 3 that can serve as the basis for future discussion, refinement and possibly adoption by the CDIO community. We wish to strongly emphasize that the paper is intended as a starting point for the discussion, not as the final decision on whether the concept of optional standards should be introduced. We also wish to emphasize that the proposed list of optional standards presented in the paper is not final in any way.

LITERATURE REVIEW

Let us start by reviewing some statements on the challenges that future engineers will need to address and the associated implications for the knowledge and skills of graduating engineers, focusing on aspects that are not addressed by the original CDIO standards.

The US National Academy of Engineering (2008) identified 14 “grand challenges” that engineers need to address during the 21st century. The challenges can be grouped Into “Sustaining life on earth”, “Living secure from threats”, “Promoting healthy living”, and “Living and learning with joy”. Al-Atabi (2013) argues that a program that prepares students to address the grand challenges needs to include research experience, to have an integrated curriculum, to train entrepreneurship, to provide a global dimension and to offer service learning.

Crawley *et al.* (2011) provided a summarized critique on the development ideas for the first version of the CDIO syllabus. The critique argued for a more visible position for knowledge and skills related to innovation, invention, sustainability, international factors, dialoguing, leadership and entrepreneurship. As a consequence, a number of changes were made to the CDIO syllabus, including new sections entitled “Leading engineering endeavors” and “Engineering entrepreneurship”. However, no additions were made to the CDIO standards.

Kamp (2014) argued that current engineering programs typically put too much emphasis on technical knowledge and processes in their curricula, while neglecting the socio-economical context in which technical solutions are only part of the solution. Kamp further identified a set of key capabilities for future engineers including creative thinking, decision-making, leadership, global mindset and interdisciplinary thinking. However, the most important capability of future engineers, Kamp concluded, is a positive approach towards life-long learning.

In the CDIO implementation survey (Malmqvist *et al.*, 2015), respondents were also asked to point out future directions for the CDIO framework. Requests were raised for formulating a vision for engineer’s work in 2030 and elaborating on the consequences for learning outcomes for engineering education, for standards suitable for assessing master programs, and for inclusion of novel pedagogical ideas and concepts, such as on-line education, to the CDIO framework.

Many authors have published ideas and approaches on how to develop these emerging skillsets. Fai (2011) and Taajamaa *et al*. (2011) have suggested to add “design thinking” methods (Rowe, 1991) to the front end of the CDIO process, thereby exposing and providing students with tools for dealing with complex, multidisciplinary problems where problem identification itself is challenging. Campbell and Beck (2010) proposed a CDIO standard for internationalization and mobility. Enelund *et al*. (2011) reported on a concept for a computational mathematics curriculum, enabling more authentic, simulation-driven mathematics training for engineering students. Enelund *et al*. (2013) presented an approach to consider sustainability aspects throughout an engineering program.

These proposals have so far not been developed as and codified into CDIO standards. (Campbell and Beck’s Internationalization and mobility standard was suggested as a CDIO standard in 2010, but not accepted at the time.) However, the examples listed above a fertile starting point for formulating additional CDIO standards, as is the aim of this paper.

DEFINITION AND IDENTIFICATION OF POTENTIAL OPTIONAL STANDARDS

In this section, we explain the concept of an optional CDIO standard and outline the requirements on such a standard to be accepted. Based on the findings in the literature review, we list a number of potential optional CDIO standards, which are then screened against the list of requirements.

We consider that the adaptation of an optional CDIO standard assumes that the original twelve, “basic” CDIO standards provide the fundamentals for a program. The basic CDIO standards form a core to which optional CDIO standards can be added to indicate a particular profile or development direction for a program, but the optional standards do not replace any of the basic standards. See Figure 1 for an illustration.

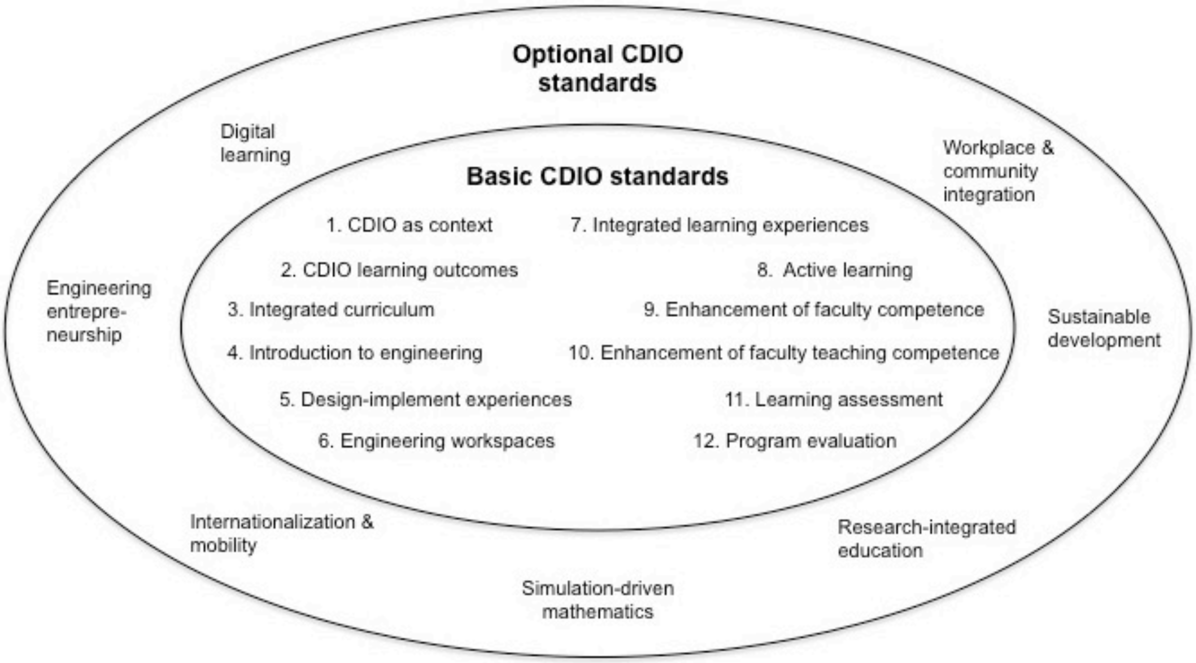

Figure 1. Basic and (proposed) optional CDIO standards

The requirements on an optional CDIO standard start from the purpose of the basic CDIO standards, i.e., to express the context and goals, the curriculum, the learning environment, the teaching, learning and assessment approaches, the faculty development support, and the quality assurance system for the program. A CDIO standard is to be used for:

- Program design
- Periodic program self-evaluation
- Benchmarking, discussions and co-development with other programs

The twelve basic CDIO standards are “best practices” scoped with the expectations on current engineering programs leading to a bachelor degree. We argue that in order to qualify as an optional CDIO standard, a pedagogical best practice should:

- Address an important, typically emerging, need in engineering education
- Be based on an novel, yet well codified, pedagogical approach, developed within or outside of the CDIO community
- Be widely applicable, i.e. not be specific to a single discipline (for example, civil engineering)
- Not be sufficiently addressed by interpretation of a current standard (such as integrated learning)
- Reflect a program-level approach, and not be obtainable by implementation in a single course
- Be evident in a substantial number of CDIO programs as a distinguishing feature
- Support the definition of a distinct program profile, beyond basic CDIO
- Be assessable by the CDIO standards rubrics

In the literature review, we identified the following potential optional CDIO standards, listed in alphabetical order:

- Digital learning (Kamp, 2014; Malmqvist *et al*., 2015)
- Diversity (Crawley *et al*., 2011)
- Engineering entrepreneurship (Crawley et al., 2011; Mäkimurto-Koivumaa & Belt, 2015)
- Engineering ethics (van de Poel & Royakkers, 2011)
- Internationalization & mobility (Campbell & Beck, 2010)
- Leadership (Crawley *et al.,* 2011)
- Master-level CDIO programs (Malmqvist *et al*., 2015)
- Multidisciplinary, collaborative skills (Kamp, 2014)
- Research-integrated education (Al-Atabi, 2013; Kamp, 2014)
- Simulation-based mathematics (Enelund *et al*., 2011)
- Sustainable development (National Academy of Engineering, 2008, Enelund *et al*., 2013)
- Workplace and community integration (National Academy of Engineering, 2008)

ELABORATION OF PROPOSED OPTIONAL CDIO STANDARDS

This section further elaborates some proposed optional CDIO standards. The format is the same as for the original standards, i.e., a standard is given a characterization, a description, a motivating rationale and a list of examples of evidence that may be used to document that the standard is being addressed.

Seven standards were chosen for elaboration in this paper, i.e., Digital learning, Engineering entrepreneurship, Internationalization & mobility, Simulation-based mathematics, Research-integrated education, Workplace and community integration, and Sustainable development, as shown in Figures 2-8. The primary criterion for selection was the availability of examples of best practice for the optional standard. The remaining potential optional CDIO standards are left for future development.

Digital learning standard

(Brockhoff, 2011; Hugo, 2014; Cheah et al., 2016; Cronhjort & Weurlander, 2016)

Engineering programs that support and enhance the quality of student learning, and teaching, through digital learning tools and environments.

Description

A program that employs digital learning technology to enhance the student learning experience as well as teaching effectiveness. Course development and delivery are assisted using appropriate e-learning development infrastructure. Program and course development is assisted by staff familiar with the CDIO framework for engineering education development, as well as expertise in instructional design, multimedia content development (recording, editing, and distribution), and assessment.

Rationale

The ability to augment learning activities through digital tools and resources provides instructors, program designers, and students with increased flexibility. The physical design of the teaching space and the duration of the contact time enable instructors to develop more interactive teaching and learning activities. Digital content repositories from prerequisite courses enable the efficient reactivation of knowledge, facilitating scaffolding across the curriculum. Program designers can structure student learning in a manner that provides increased learning flexibility including student mobility.

Evidence

- Courses within a program that use digital learning methods for either partial or full lecture content delivery
- Learning environments that support blended or flipped course delivery, enabling instructor-student contact time to be used for higher-level learning activities including project-based learning, inquiry-based learning, and active learning,
- Digital support of novel curriculum structures including coursework on internship or during non-residential study semesters
- Infrastructure and resources that support the design, development, and distribution of digital content

Figure 2. Digital learning standard

Engineering entrepreneurship standard
(based on section 4.8 in CDIO syllabus 2.0 (Crawley et al., 2011) and inspired by Mäkimurto-Koivumaa & Belt, 2015)

Engineering programs that actively develop their graduate’s abilities to, in addition to conceive, design, implement and operate complex products, systems and processes, to commercialize technology and to create business ventures based on new technology.

Description
A curriculum that is permeated with entrepreneurial learning experiences. Entrepreneurial competence is developed *through* entrepreneurship learning activities (e.g. by students performing value creation projects in the community), by learning about entrepreneurship (e.g., marketing, intellectual property rights), by learning *in* entrepreneurial settings (e.g., student incubators or student-run companies) and *learning* for entrepreneurship (e.g. business model creation tools). The entrepreneurial learning is supported by adapted learning environment and by staff with entrepreneurial competence.

Rationale
The role of engineers has broadened from designing and implementing technical solutions to forming business ventures based on technological innovations. Startups are increasingly based on ideas developed by students during their studies, or on ideas and intellectual property owned by university researchers that students further develop and commercialize. The needed competences include opportunity identification, business planning, intellectual property rights, company financing and marketing.

Evidence

- Program goal documents that identify entrepreneur as a potential professional role for the program’s graduates
- Specific and detailed program learning outcomes related to engineering entrepreneurship knowledge, skills and attributes, including, for example, business plan development, company capitalization and marketing
- Learning activities about, for, in and through entrepreneurship are visible in multiple places in the curriculum
- Learning environments that support education for entrepreneurship, such as student business incubators
- Data on students or recent graduates who start companies based on technical ideas that they have developed themselves or acquired from university researchers

Figure 3. Engineering entrepreneurship standard

Internationalization & mobility standard
(proposed by Campbell & Beck (2010))

Programs and organizational commitment which exposes students to foreign cultures, and promotes and enables transportability of curriculum, portability of qualifications, joint awards, transparent recognition and international mobility.

Description: CDIO Program Internationalization and Mobility encourages and recognizes organizational commitment, which prepares engineers for a global environment and to expose them to a rich set of international experiences and contexts during their studies. It represents the exposure, promotion, facilitation, opportunity and scholarship of an internationalized curriculum, qualifications and international mobility of students.

Rationale: Graduate engineers of the future will increasingly need to be international in their outlook and experience, and be prepared to operate globally. Businesses have to compete and collaborate on a global scale, and operate across national and international borders with organizational environments being increasingly complex, dynamic and with more interdependencies. Our challenge as educational institutions is to aid our students to prepare for this global environment.

Evidence may include, non-exclusively, one or more of the following:

- The embedding of authentic cultural awareness and experiences within the curriculum, or social activities
- Opportunities made available for students to learn second languages
- Programs which encourage and recognize study abroad, and other international experiences (including internships, exchanges) for credit
- Establishment of a mobility window within programs and curriculum
- An ePortfolio facility, which links student learning outcomes with artifacts, and graduate attributes and competencies, which are recognized through international accords.
- A demonstrable and tangible institutional commitment to internationalization and student mobility
- Complementary partnerships between international universities
- Transparent expectations of student learning outcomes from an international experience
- International benchmarking of programs
- Active involvement in international engineering education scholarly activities
- Program accreditation with international cross-accreditation
- Transparency in institutional cross-credit for study abroad

Figure 4. Internationalization and mobility standards

Simulation-based mathematics standard
(Enelund et al., 2011)

Engineering programs for which the mathematics curriculum is infused with programming, numerical modeling and simulation from the start.

Description
Basic mathematics courses mix the learning of mathematical lemmas and methods with direct practice of numerical program solving, aided by mathematical software. Mathematics courses teach programming of algorithms for equation solving.

Rationale
The mathematics courses will include more authentic and complex problems. Realistic decision-making situations can be simulated. The connection to science and engineering courses can be reinforced. A better understanding of what advanced mathematics can be used for and how that it carried out strengthens student motivation.

Evidence

- Specific and detailed program learning outcomes address mathematical programming, modeling and simulation
- Specific and detailed course learning outcomes address mathematical programming, modeling and simulation
- The programme idea brings forward advanced simulation skills as distinctive skill of its graduates
- Use of mathematical software in basic mathematical courses
- Common, mutually-supporting, simulation-based assignments in mathematics and engineering science courses

Figure 5. Simulation-based mathematics standard

Research-integrated education standard
(Gierke et al., 1998; King et al., 1999; Jenkins & Healey, 2005; Magnell, Söderlind & Geschwind, 2014)

Engineering programs that include one or more research experiences as part of student learning.

Description
A program that includes contact with research, such as research-tutored, research-based or research-oriented learning experiences (Healey, 2005). In hands-on open-ended experimental activities, students are provided with access to a laboratory with appropriate equipment to investigate problems, processes or phenomena.

Rationale
Through open-ended knowledge discovery experiences, students can form pro-active habits for learning, and for critical and creative thinking, i.e. the life-long learning skills necessary in a changing world. Students need to be exposed to active researchers as role-models, to approaches and methods for building new knowledge, to searching, reading and using scientific literature, and to forms of research collaboration, e.g. networks and environments. Students also need to develop the ability to conduct unscripted laboratory experiences, i.e. an experiment that includes the design, set up, collection and analysis of data, and formulation of conclusions. Details of how to proceed with the experiment are not provided to the student, but instead the student is expected to formulate their own experimental plan. This provides them with a student-centered learning experience that is not typically delivered through traditional scripted laboratories.

Evidence
- Junior research projects
- Assessment through student conferences
- Students assigned to research labs and projects
- One or more teaching and learning activity that involves open-ended experimentation
- Student independence in the planning of the experiment
- Learning environments that support open-ended experimentation on a specific problem, process or phenomenon
- Student research assistant internships

Figure 6. Research-integrated education standard

Workplace and community integration standard
(Hughes, 2004; Jonassen et al., 2006; Jamison et al., 2014; Jonassen, 2014; Henriksen, 2014, Eckert et al., 2015)

Engineering programs that actively develop their graduates' abilities to identify and address authentic and open-ended problems, in authentic settings, interacting with stakeholders.

Description
A curriculum that is permeated with learning experiences in which students address real and open-ended problems in workplace or community contexts, interacting with relevant stakeholder groups. The aim is to develop students' ability to interpret needs and formulate problems that can include multiple and often conflicting goals, contextual constraints and criteria, and require transdisciplinary approaches as well as collaboration and dialogue in various compositions. The aim is also to support students' mature reflection on their role and responsibilities as engineers, and on the implications of science and technology in society.

Rationale
Together with the acquisition of disciplinary knowledge and personal, interpersonal and product, process and system building skills, students also need to develop the ability to apply these in realistic settings and conditions. To prepare graduates for engineering practice, students need experience of working in authentic settings, addressing authentic needs, and interacting with various stakeholders. At least some of this learning should be experience-based, i.e. not only learning *about* such work in theory, but also learning from working *in* relevant roles in authentic settings. Development of technology is increasingly based on intensive dialogue and collaboration with problem stakeholders, e.g. users, and therefore it is important to practice various forms of communication and collaboration, also with people who are not engineers. Further, if the education communicates an unnecessarily reductionist view on problems and methods for addressing them, graduates may come to see engineering only as creating purely technical solutions to purely technical problems. Education must prepare students for working with problems that may also contain political, economic, social, legal, ethical, and aesthetic aspects, often resulting in conflicting values, conditions, constraints, and criteria for evaluating alternative solutions.

Evidence:
The program contains opportunities for relevant learning activities, for instance through:

- Work-based learning experiences
- Co-op educational models
- Challenge-driven education
- Needs-driven projects
- Applying user involvement methods
- Community service projects
- Reflection on such experiences

Figure 7. Society and workplace-integrated standard

Sustainable development standard
(based on Enelund et al. 2013)

A program that identifies the ability to contribute to a sustainable development as a key competence of its graduates. The program is rich with sustainability learning experiences, developing the knowledge, skills and attitudes required to address these challenges.

Description: The curriculum features sustainability learning experiences on basic as well as advanced level. Sustainability is addressed both in dedicated course(s) and as integrated learning experiences included in disciplinary courses and projects. The curriculum offers opportunities for students to specialize in sustainable development on the advanced (master) level.

Rationale: To address the issues of sustainability is a key challenge for mankind. Engineers need to understand the implications of technology on social, economic and environmental sustainability factors, in order to develop appropriate technical solutions as well as to collaborate with other actors in addressing sociotechnical issues.

Evidence may include, non-exclusively, one or more of the following:

- Specific and detailed program learning outcomes address social, economic and environmental sustainability
- Specific course learning outcomes address social, economic and environmental sustainability
- Curriculum with dedicated sustainability courses as well and integrated sustainability learning experiences
- Documented progressive sustainability learning sequences across several courses and projects
- Master programs offering opportunities to specialize in sustainability

Figure 8. Sustainable development standard

DISCUSSION

Are optional standards necessary?

Several of the optional standards above are related to particular learning outcomes, already represented in the CDIO Syllabus. It can therefore be argued that the relevant learning outcomes can be included and elaborated in programme objectives, and implemented already through the “basic” standards or in “conventional” ways. That is of course true, and such normal level of implementation may be sufficient for many, if not most, programs. However, it does not make it unnecessary to explicitly address their implementation in the standards. First of all, we find that when these aspects are taken seriously, they may all necessitate particular forms of education, in multiple courses. We see a parallel in Standard 5 Design-implement experiences and 6 Engineering workspaces, which explicitly address how to realize the activities in the curriculum for learning a particular set of key skills (among them 4.3-4.6 in the Syllabus), while in theory they could have been addressed through standard 7 Integrated learning experiences, and 8, Active and Experiential Learning. Further, we recognize that instead of just listing the related learning outcomes among others, institutions often have legitimate needs to make these aspects highly visible. An official declaration to include any of these optional standards implies a clear commitment. Not only does it communicate a profile, but it also creates impetus through identifying directions for change and direct monitoring through self-evaluation.

Relationship between standards

To some extent the optional standards are overlapping with each other, and with existing standards. It would for instance be fully possible to devise a project-based learning activity according to Standard 5, which also addresses one or more optional standards. The intention is not, however, that a few curriculum elements can tick all the boxes.

We further find that the adoption of any of these optional standards may slightly change the interpretation of other standards. For instance, any of the optional standards will imply a need to develop the relevant faculty competences, i.e. regarding what to teach, Standards 9 Enhancement of faculty competence, and regarding how to teach, standard 10 Enhancement of faculty teaching competence. While this may require substantial effort, we have not proposed a new faculty development standard accompanying each of the optional standards. Instead, we suggest that such needs could be accommodated through reinterpretation of standard 9 and 10, without changing their current definitions.

Deciding on optional standards

We propose that the principles suggested here for expanding the standards, as well as the formulations of the first optional standards, should be subject to discussion within the CDIO community, and to be recognized as official they should be submitted for approval by the CDIO Council. A similar process should apply to any collaborators who want to suggest additional optional standards. Over time, one or more of the optional standards may well prove to be so broadly accepted, that an amendment to the “basic” standards could be warranted.

Using optional standards to strengthen the CDIO community

We anticipate that the optional standards can create meeting points within the CDIO community for educators with special interests, both those who are keen to learn more in order to take their first steps, and experienced implementers who are interested in sharing and developing their practices. This may serve to advance the CDIO community as a natural arena to widely disseminate important work within engineering education.

CONCLUSIONS & FUTURE WORK

Emerging and evolving expectation on the competences of graduating engineers as well as new pedagogical approaches and tools motivate the extension of the CDIO framework with "optional" CDIO standards. The paper shows that a number of potential optional CDIO standards can be identified and formulated in a similar fashion as the existing basic CDIO standards.

The optional CDIO standards can be useful for a CDIO program to clarify its pedagogical profile, beyond the basic CDIO program characteristics. Optional CDIO standards also serve the purposes of structuring knowledge sharing within the CDIO Initiative and may guide the development of the CDIO framework.

The selection and formulation of the proposed optional CDIO standards should be considered as first drafts, to be further evaluated and refined through discussions in the CDIO Initiative prior to acceptance.

REFERENCES

Al-Atabi, M. (2013). Grand Challenges for Engineering and Development of CDIO Skills. *Proceedings of the 9th International CDIO Conference*, Cambridge, MA, USA.

Bennedsen, J., Georgsson, F., & Kontio, J. (2016). Updated Rubric for Self-Evaluation (v 2.1). *Proceedings of the 12th International CDIO Conference*, Turku, Finland.

Brockhoff, P. B., (2011). Taking the Classical Large Audience Lecture Online Using Tablet Computer and Web Conferencing Facilities, *Proceedings of the 7th International CDIO Conference*. Lyngby, Denmark.

Brodeur, B., & Crawley, E. F. (2005). Program Evaluation Aligned With the CDIO Standards. *Proceedings of the 2005 ASEE Conference.*

Campbell, D. & Beck, H. (2010). Toward Internationalized Engineering Curriculum and Student Mobility. *Proceedings of the 6th International CDIO Conference*, Montréal, Canada.

Cheah, S-M., Lee, H-B. & Sale, D. (2016). Flipping a Chemical Engineering Module Using Evidence-Based Teaching Approach, *Proceedings of the 12th International CDIO Conference,* Turku, Finland.

Crawley, E. F., Malmqvist, J., Lucas, W., & Brodeur, D. (2011). The CDIO Syllabus v2.0. An Updated Statement of Goals for Engineering Education. *Proceedings of the 7th International CDIO Conference*, Lyngby, Denmark.

Crawley, E. F., Malmqvist, J., Östlund, S., & Brodeur, D. (2007). *Rethinking Engineering Education: The CDIO Approach*, 1st edition. New York: Springer-Verlag.

Crawley, E., F. Malmqvist, J., Östlund, S., Brodeur, D., & Edström, K. (2014). *Rethinking Engineering Education: The CDIO Approach*, 2nd edition. New York: Springer-Verlag.

Cronhjort, M., Weurlander, M. (2016). Student Perspectives on Flipped Classrooms in Engineering Education. *Proceedings of the 12th International CDIO Conference*, Turku, Finland.

Eckert, G., Brobäck, J., Nero, K., & Hjelmåker, M. (2015). Ett år med näringslivsförlagd kurs för alla programstudenter [A Year of Workplace-based Course for all Program Students]. *Proceedings of the 5:e Utvecklingskonferensen för Sveriges ingenjörsutbildningar*, Uppsala, Sweden, 63-66.

Enelund, M., Larsson, S., & Malmqvist, J. (2011). Integration of Computational Mathematics in the Mechanical Engineering Curriculum. *Proceedings of the 7th International CDIO Conference*, Lyngby, Denmark.

Enelund, M., Knutson Wedel, M., Lundqvist, U., & Malmqvist, J. (2013). Integration of Education for Sustainable Development in the Mechanical Engineering Curriculum. *Australasian Journal of Engineering Education*, *19*(1), 1-12.

Fai, S.K. (2011). An Observational Study of Infusing Design Thinking into the CDIO Framework. *Proceedings of the 7th International CDIO Conference*, Lyngby, Denmark.

Gierke, J.S., Mayer, A.S., & Shonnard, D.R. (1998). Multidisciplinary Subsurface Remediation Courses: Fundamentals, Experiments, and Design Projects, *Journal of Engineering Education*, 555-565.

Jenkins, A., & Healey, M. (2005). *Institutional Strategies to Link Teaching and Research*. York: Higher Education Academy.

Henriksen, L. B. (2014). Knowledge Work and the Problem of Implementation - The Case of Engineering. In D. Jemielniak (Ed.), *The Laws of the Knowledge Workplace: Changing Roles and the Meaning of Work in Knowledge-intensive Environments* (pp. 35-54). Burlington: Gower.

Hughes, T. P. (2004). *Human-built World: How to Think about Technology and Culture*. Chicago: University of Chicago Press.

Hugo, R.J. (2014). From the Printing Press to You Tube – Welcome to the World of Lecture 2.0. *Proceedings of the 10th International CDIO Conference*, Barcelona, Spain.

Jamison, A., Kolmos, A. & Holgaard, J. E. (2014). Hybrid Learning: An Integrative Approach to Engineering Education. *Journal of Engineering Education*, *103*(2), 253-273. doi:10.1002/jee.20041.

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday Problem Solving in Engineering: Lessons for Engineering Educators. *Journal of Engineering Education*, *95*(2), 139-151.

Jonassen, D. H. (2014). Engineers as Problem Solvers. In Johri, A., & Olds, B.M. (Eds.), *Cambridge Handbook of Engineering Education Research*. New York, NY: Cambridge University Press.

Kamp. A. (2014). *Engineering Education in a Rapidly Changing World – Rethinking the Mission and Vision on Engineering Education at TU Delft*. Technical Report, Delft University of Technology, Delft, The Netherlands.

King, R. H., Parker, T. E., Grover, T. P., Gosink, J.P., Middleton (1999). N.O.T., A Multidisciplinary Engineering Laboratory Course. Journal of Engineering Education, *July*, 311-316.

Magnell, M., Söderlind, J., & Geschwind, L. (2016). Teaching-research Nexus in Engineering Education, *Proceedings of the 12th International CDIO Conference,* Turku, Finland.

Malmqvist, J., Hugo, R., & Kjellberg, M. (2015). A Survey of CDIO Implementation Globally - Effects on Educational Quality. *Proceedings of 11th International CDIO Conference*. Chengdu, China.

Mäkimurto-Koivumaa, S. & Belt, P. (2015). About, for, in or through Entrepreneurship in Engineering Education. *European Journal of Engineering Education, 41*(5), *512-529.*

National Academy of Engineering (2008). *14 Grand Challenges for Engineering*, http://www.engineeringchallenges.org/8996.aspx, accessed on January 26, 2017.

Rowe, P. G. (1991). *Design thinking*. Cambridge, MA: MIT Press.

Taajamaa, V., Eskandari, M., Karanian, B., Airola, A., Pahikkala, T., & Salakoski, T. (2016). O-CDIO: Emphasizing Design Thinking in the CDIO Engineering Cycle, *International Journal of Engineering Education*, *32*(3B), 1530-1539.

Van de Poel, I., & Royakkers, L. (2011). *Ethics, Technology and Engineering – An Introduction*. London: Wiley-Blackwell.

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