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OPTIONAL CDIO STANDARDS: SUSTAINABLE DEVELOPMENT, SIMULATION-BASED MATHEMATICS, ENGINEERING ENTREPRENEURSHIP, INTERNATIONALISATION & MOBILITY

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ABSTRACT

An effort to update the CDIO Standards from version 2.1 to 3.0 was started in 2017 (Malmqvist et al., 2017) and further outlined in 2019 (Malmqvist et at., 2019). The aims were to incorporate external changes to the context of engineering education, to address criticism that had been raised against earlier versions of the standards, and to establish an extendable CDIO framework architecture. The work has resulted in that the original twelve CDIO standards, from now on named "core" CDIO standards, will be complemented by "optional" CDIO standards, that codify additional educational best practices that have been developed within the CDIO community in the same format as the original CDIO standards. Eleven optional standards have been proposed (Malmqvist et al., 2019). This paper accounts for the elaboration of the subset of the proposed optional standards that were recommended for further development by the CDIO Council in November 2019. These recommended optional standards are presented as full texts, i.e., including descriptions, rationale and rubrics. The described optional standards are: *Sustainable development*, *Simulation-based mathematics*, *Engineering entrepreneurship* and *Internationalization & mobility*.

KEYWORDS

Sustainable development, Simulation-based mathematics, Engineering entrepreneurship, Internationalization, Standards 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

INTRODUCTION

The CDIO standards were initially introduced in 2005 (Brodeur & Crawley, 2005) and presented more extensively by Crawley *et al*. (2007). The Standards constitute a set of principles or best practices underlying the implementation of the CDIO syllabus in an engineering program. The standards define the distinguishing features of a CDIO program, serve as guidelines for educational reform, enable benchmarking with other CDIO programs and provide a tool for self-evaluation-based continuous improvement.

Since 2007, the standards have been updated twice: CDIO standards 2.0 were adopted in 2014 (Crawley *et al.*, 2014) and the rubrics have been further modified (Bennedsen *et al.*, 2016), resulting in CDIO standards 2.1. These modifications have been relatively minor and have not changed the scope or the main contents of the standards.

Nevertheless, Malmqvist *et al*. (2017) pointed out that as engineering education best practice and the context of engineering are continuously evolving, also the CDIO approach must be evolved. They further argued that the CDIO framework could become more flexible and open by introducing an additional category of standards, named "optional CDIO standards", which would be added to the original twelve standards, now called "core CDIO standards". Since then, a number of proposals for optional CDIO standards have been put forward (Malmqvist *et al*., 2019), and the CDIO Council has decided on a process for screening the proposals and working with them for possible inclusion in the CDIO framework.

In parallel with this work, the core CDIO standards are also being updated (see Malmqvist *et al*., 2020). One difference is that modifications to the core standards are undertaken with some caution, since they should be adopted in consensus and all CDIO programs are expected to aim for their fulfilment. In contrast, the optional standards are freely pursued by those CDIO members that find them relevant for their context and conditions, and appropriately reflecting their ambitions to lead the way.

In the remainder of this paper, we first account for the criteria that a CDIO optional standard should fulfil and the process for their proposal, review and acceptance-decision. Descriptions of a first set of optional standards are then provided. A discussion section suggests future work with some other proposals.

OPTIONAL CDIO STANDARDS FRAMEWORK

The optional CDIO standards framework consists of two elements: The first is a set of criteria that optional standards should fulfill, while the second is a process for proposing, reviewing and possibly adopting an optional standard.

Criteria

The criteria that a potential optional CDIO standard should fulfil were proposed by Malmqvist *et al*. (2017). A slightly revised version of their list follows:

- Address an important, typically emerging, need in engineering education.
- Be based on a 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 (e.g., civil engineering).

- Not be sufficiently addressed by interpretation of a core standard.
- Reflect a program-level approach, and not be obtainable by implementation in a single course.
- Reflect ongoing development in a number of CDIO programs.
- Provide inspiration and guidance for CDIO programs and institutions in taking the lead in the areas addressed by the optional standard.
- Support the definition of a distinct program profile, beyond basic CDIO implementation.
- Be assessable by the CDIO standards rubrics.

Process for proposal, review and acceptance

Malmqvist *et al*. (2019) outlined a process to facilitate an open, transparent and controlled way for proposing, reviewing and deciding on the acceptance of optional CDIO standards. The process has four main steps. The first is that a proposal for an optional CDIO standard is codified in a paper that is presented at a CDIO conference and thus archived in the CDIO Knowledge Library. Any member of the CDIO community may submit such a paper. In conjunction with the conference, the proposal will be reviewed by the CDIO Council. The outcome of that discussion may be actions for further review and development to prepare the new optional CDIO standard, or the proposal can be rejected. The following year, the CDIO Council will analyze the review recommendations and possibly modifications made in response to them and decide on the acceptance of the proposal. Figure 1 is a graphical representation of the process.

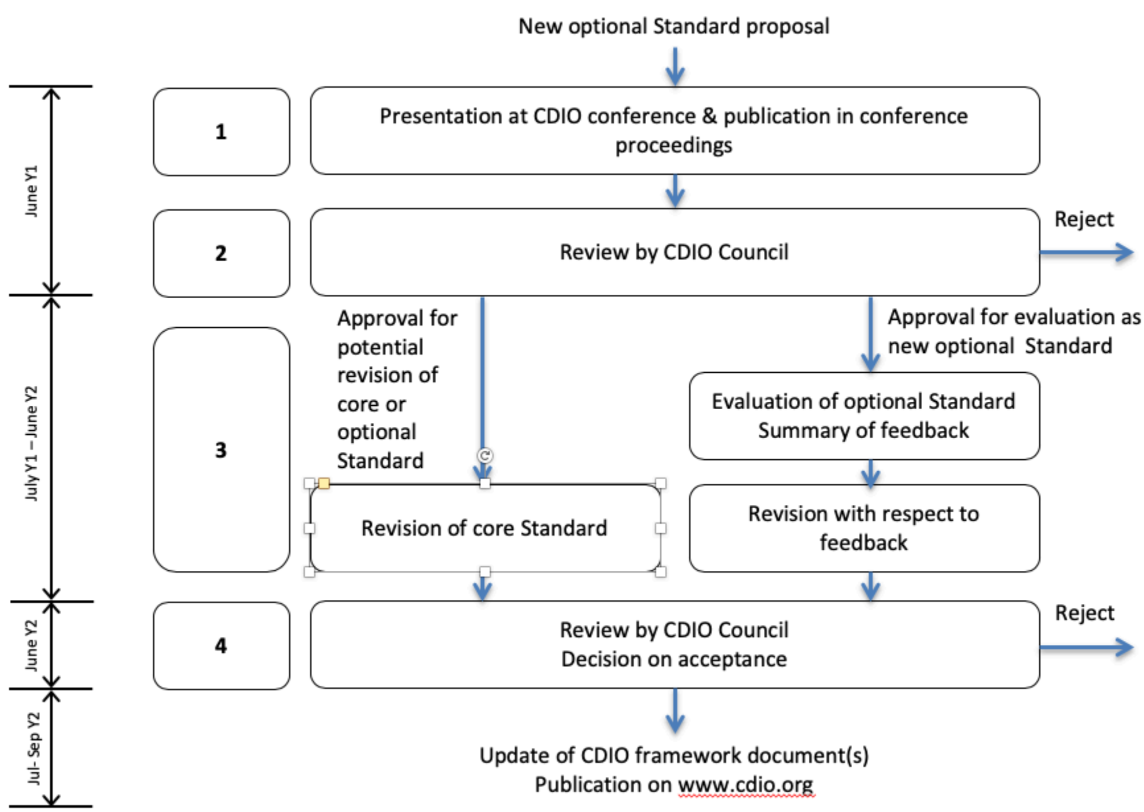

Figure 1. Optional Standards evaluation and approval process.

PROPOSALS FOR OPTIONAL STANDARDS

Malmqvist *et al*. (2019) summarized the propositions for optional Standards, 11 in total (Table 1). Three categories of proposals were identified: proposals linked to major societal trends, proposals linked to practices for outreach and collaboration, and finally proposals that suggest expansions of the scope of the standards.

During the Fall of 2019, the proposed optional standards were distributed for review in the CDIO community. The feedback was discussed during the 2019 CDIO International Working meeting in Singapore. With consideration of the feedback, the CDIO Council chose four proposals for optional standards to be further refined and complemented (for example with dedicated rubrics), and to be put forward for a possible formal adoption by the CDIO Council at the 2020 International CDIO Conference. This preparation is the scope of this paper. The four proposals are *Sustainable development*, *Simulation-based mathematics*, *Engineering entrepreneurship* and *Internalization & mobility*, as listed in the following section.

In addition, the CDIO Council recommended a deeper analysis of the proposals *Industry engagement*, *Workplace learning* and *Workplace and community integration*, considering several alternatives: Integration into the texts of the core standards, merging or separate elaboration. This is essential future work, however outside of the scope of the current paper.

Table 1: Proposed optional standards (Malmqvist *et al*., 2019).

Title		**Short description**	**Sources**
Strategic trends	Sustainable development	A program that identifies the ability to contribute to 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 sustainability challenges.	Malmqvist *et al*., 2017; Enelund *et al.* 2013
	Digital learning	Engineering programs that support and enhance the quality of student learning, and teaching, through digital learning tools and environments.	Malmqvist *et al*., 2017
	Simulation-based mathematics	Engineering programs for which the mathematics curriculum is infused with programming, numerical modeling and simulation from the start.	Malmqvist *et al*., 2017; *Enelund et al., 2011*
	Engineering entrepren-eurship	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.	Malmqvist *et al*., 2017; *Mäkimurto-Koivumaa & Belt, 2015*
Outreach & collaboration	International-ization & mobility	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.	Campbell & Beck, 2010
	Research-integrated education	Engineering programs that include one or more research experiences as part of student learning.	Malmqvist *et al*., 2017
	Industry engagement	Actions that education institutions undertake to actively engage industry partners to improve its curriculum.	Cheah & Leong, 2018

	Workplace learning	A curriculum that includes students working in a real-world work environment with the aims of strengthening in-campus learning and developing their professional identity.	Cheah & Leong, 2018
	Workplace and community integration	Engineering programs that actively develop their graduates' abilities to identify and address authentic and open-ended problems, in authentic settings, interacting with stakeholders.	Malmqvist *et al.*, 2017
Expanding scope / coverage	Student success	A curriculum supported in the analysis and synthesis of information allowing taking effective actions to mitigate the risk and vulnerability in the student population; with strategies focused on the prevention of drop out and that guarantee student success.	Gonzales *et al.*, 2018
	Foresight – Forecast – CD(IO)	Revision of all CDIO Standards to fit frame of master and PhD programs. This implies elaborating on product (etc.) lifecycle stages prior to Conceiving, referred to as Foresighting and Forecasting.	Chuchalin, 2018

THE FOUR FIRST CDIO OPTIONAL STANDARDS

This section lists the full definitions of the first optional CDIO standards, including descriptions, rationale and rubrics.

Sustainable development

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 sustainability challenges.

Description

The program emphasizes environmental, social and economic sustainability in the adoption of the CDIO principles as the context for engineering education (Standard 1). Sustainability related knowledge, skills and attitudes, are explicitly addressed in program goals and learning outcomes (Standard 2). Aspects of sustainable development are integrated in several mutually supporting disciplinary courses and projects, possibly in combination with specific sustainability courses (Standard 3). Concepts of sustainability, potentials and limitations of science and technology and related roles and responsibilities of engineers, are established at an early stage of the education (Standard 4). Design-implement experiences provide students with opportunities to apply and contextualize sustainability knowledge, skills and attitudes, both in the development of new technology and in the reuse, redesign, recycling, retirement, etc., of existing technology (Standard 5). Physical and digital learning environments enable interdisciplinary and transdisciplinary collaborative learning and interaction with various external stakeholders (Standard 6). Sustainability learning experiences are integrated with the learning of disciplinary knowledge, personal and interpersonal skills, and product, process, system and service building skills (Standard 7). Active experiential and transformative learning activities develop students' key competences for sustainability (Standard 8). Enhancement of faculty competences for sustainability and related teaching competences is actively promoted (Standard 9 & 10). Approaches appropriate for assessing sustainability related learning outcomes are implemented (Standard 11). The integration of sustainable development is evaluated by students, faculty, industry and societal stakeholders, and in relation to relevant UN and other frameworks (Standard 12).

Rationale

To address the issues of sustainability is a key challenge for humanity. Engineers need to understand the implications of technology on social, economic and environmental sustainability factors, in order to develop appropriate technical solutions in collaboration with other actors in addressing societal issues.

Rubric for self-assessment

5	Sustainable development is fully integrated in accordance with the description in the optional CDIO standard for sustainable development.
4	The integration of sustainable development is pervasive, well adapted to the program context, promoting progression of knowledge, skills, and attitudes, and there is documented evidence that students have achieved the related intended learning outcomes.
3	There are explicit program goals and intended learning outcomes related to environmental, social, and economic sustainability and at least three substantial sustainable development learning experiences of increasing complexity including an introduction early in the program.
2	At least one substantial sustainable development learning experience is being implemented and there is a plan for extended integration of sustainable development.
1	Minor sustainable development learning experiences have been implemented and needs and opportunities for extended integration of sustainable development have been identified.
0	There are no sustainable development learning experiences in the program.

Simulation-based mathematics

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

Description

The program emphasizes the importance of simulation-based mathematics in engineering education, research and practice. The program idea brings forward advanced simulation skills as distinctive skill of its graduates. Mathematical programming, modeling and simulation knowledge and skills are explicitly addressed in program and course goals and learning outcomes. 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. Common, mutually-supporting, simulation-based assignments connect mathematics and engineering science courses. Planned learning sequences for advancing mathematical modeling and simulation skills throughout the curriculum. Design-implement experiences are designed to, in addition to develop hands-on prototyping skills, reinforce and enhance mathematical modeling and simulation concepts and competencies.

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.

Rubric for self-assessment

5	The course/module and program learning outcomes for mathematical programming, modelling and simulation are regularly evaluated and revised, based on feedback from students, instructors, and other stakeholders.
4	There is documented evidence that students have achieved the intended learning outcomes for mathematical programming, modelling and simulation.
3	Course and/or program learning outcomes for mathematical programming, modelling and simulation are validated with key program stakeholders, including faculty, students, alumni, and industry representatives and levels of proficiency are set for each outcome.
2	A plan to incorporate explicit statements of learning outcomes at course/module level as well as program outcomes for mathematical programming, modelling and simulation is accepted by program leaders, engineering faculty, and other stakeholders.
1	The need to create or modify learning outcomes at course/module level and program outcomes for mathematical programming, modelling and simulation are recognized and such a process has been initiated.
0	There are no explicit program learning outcomes at course/module level nor program outcomes that cover mathematical programming, modelling and simulation.

Engineering entrepreneurship

Engineering programs that actively prepare graduates for creating technology-based business ventures, in order to produce economic and other values for society.

Description

A curriculum that is permeated with entrepreneurial learning experiences, tailored to the relevant learning goals as defined in Standard 2. 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 learning experiences are supported by appropriate learning environments, for example various kinds of maker spaces, and by staff with entrepreneurial competence. Throughout the curriculum, projects can be made increasingly authentic and realistic. They can allow students to make real-world connections and interacting with stakeholders. Some projects may involve co-creating solutions with clients or users. Valuable learning occurs not only through the hands-on activities, but also when the students *reflect* on their experiences, including their processes and methods, successes and setbacks. This is furthered by teacher-facilitated opportunities for reflection.

Rationale

The role of engineers has broadened from designing and implementing technical solutions to also forming business ventures based on technological innovations, thereby creating value for society. 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 for example opportunity identification, business planning, intellectual property rights, company financing and marketing. Entrepreneurial learning activities can be designed to address not only students' abilities in relation to venturing, but also, simultaneously, many learning outcomes that are broadly desired in all engineering programs, such as personal and interpersonal skills, and other engineering skills.

Rubric for self-assessment

5	The entrepreneurial learning experiences are regularly evaluated and revised, based on feedback from students, instructors, and other stakeholders.
4	There is documented evidence that students have achieved the intended learning outcomes of the entrepreneurial learning experiences.
3	At least two design-implement experiences of increasing complexity are being implemented.
2	There is a plan to develop entrepreneurial learning experiences at basic and advanced level.
1	A needs analysis has been conducted to identify opportunities to include entrepreneurial experiences in the curriculum.
0	There are no entrepreneurial learning experiences in the engineering program.

Internationalization & mobility

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

The institution demonstrates a tangible organizational commitment to internationalization and student mobility. It enunciates the exposure, promotion, facilitation, opportunity and scholarship of an internationalized curriculum, qualifications and international mobility of students. Curricula which prepare engineers for a global environment and exposes them to a rich set of international experiences and contexts during their studies. Student learning outcomes include attributes and competencies which are recognized through international accords. Authentic cultural awareness learning experiences are embedded within the curriculum or social activities. Opportunities are made available for students to learn second and third languages. Study abroad and other international experiences (including internships, exchanges) are encouraged and recognized, for credit. Institutional cross-credit for study abroad is transparent. The institution establishes partnerships with international universities, benchmarks programs internationally and is actively involved in international engineering education scholarly activities.

Rationale

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

Rubric for self-assessment

5	Program Internationalization and student mobility outcomes are regularly evaluated and revised, based on feedback from students, instructors, and other stakeholders.
4	There is documented evidence that students have achieved the intended learning outcomes related to an internationalized Program.
3	The plan for internationalized learning outcomes and opportunities for meaningful student mobility embedded within the Program has been implemented.
2	A plan for internationalizing the Program and opportunities for student mobility to be embedded within the Program has been approved and a process to implement the plan has been initiated
1	The need for internationalization of the Program and opportunities for student mobility is recognized and a planning process initiated.
0	There is no aspect in the Program that provides a framework for students to develop internationalized practice or key skills, nor to engage in meaningful mobility opportunities within the curriculum.

CONCLUSIONS & FUTURE WORK

Provided that the proposed optional standards in this paper are accepted by the CDIO Council, the CDIO framework will be complemented by the concept of optional standards, and, specifically, with a first set of four adopted optional CDIO standards.

The concept of optional standards provides a pathway for the flexible extension of the CDIO framework. The associated process for review and decision secures that adopted CDIO standards are relevant, fulfil a published set of quality criteria and complementary with respect to already existing CDIO standards.

The optional standards that the CDIO Council has selected as the first candidates for adoption address sustainability, simulation-based mathematics, entrepreneurship and internationalization. These additions can be argued to reflect changed perceptions of the role and context of engineers and engineering. Now and in the future, the engineering profession will need to broaden the focus from mainly taking responsibility for technical function and product performance to a responsibility for the social, economic and environmental consequences of technology. Moreover, engineers are playing more substantive roles in social and commercial venture creation. Few engineers today work in a purely national context. International collaboration is essential all through the product lifecycle, including customer needs elicitation, product design, manufacture, use, recycling and retiring. Simulation-based mathematics is essential for exploiting the opportunities offered by digitalization and artificial intelligence. Thus, implementation of these four standards in an engineering program will better prepare its graduates for the future.

The adoption of four optional standards should be seen as a first step. There are multiple other optional standards proposals that can be further developed, reviewed and possibly adopted by the CDIO Council. At the same time, it is also important to follow up the impact of the first four. In what CDIO programs have they been implemented, what are levels of fulfilment of the standard rubrics, what concrete effects can be observed? Also, what can count as evidence of fulfillment of core and optional standards? As the CDIO community implements these optional Standards in CDIO programs, we urge them to document the work and share their experiences, in particular reflecting on the usefulness of the new standards for future refinement and development.

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BIOGRAPHICAL INFORMATION

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