MAPPING THE CDIO SYLLABUS TO THE UNESCO KEY COMPETENCIES FOR SUSTAINABILITY

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ABSTRACT

In this paper, a framework of key competencies for sustainability defined by UNESCO is used to evaluate the relevance of the CDIO Syllabus for promoting engineering education for sustainable development. The evaluation is performed in two steps. First, topics, terms and concepts in the CDIO Syllabus that corresponds to the different UNESCO key competencies are identified. The second step is a qualitative discussion where areas of strong mapping are highlighted and aspects that could be better visualized or strengthened in or added to, the Syllabus is identified. Differences in definitions of various concepts between the CDIO Syllabus and the UNESCO key competencies and the overall relation between the two frameworks are discussed. It is concluded that the CDIO Syllabus is rather well aligned with the UNESCO framework, however several opportunities (not to say needs) for strengthening the Syllabus in relation to the key competencies are identified. The UNESCO key competencies are found to be useful instruments for scrutinizing and updating the CDIO Syllabus. Other opportunities for knowledge and methods transfer between the Education for Sustainable Development (ESD) domain and the Engineering Education domain are identified. The paper is proposed to be used as basis for updating the CDIO Syllabus into a version 3.0 for maintaining its relevance in a changing world.

KEYWORDS

CDIO Syllabus, key competencies, sustainable development, ESD, Standards 1-3, 5, 7-9.

INTRODUCTION

Through the adoption of the UN 2030 Agenda (UN 2015), the global society and governments all over the world have agreed on the urgent need for change and formulated common Sustainable Development Goals (SDG). One of the seventeen SDGs considers education. To further promote the role of education for achieving the SDGs, UNESCO has issued guidelines for formulating learning objectives for each of the SDGs (UNESCO 2017). These learning objectives are based on eight key competencies for sustainability, which are derived by synthesising current research on education for sustainable development (e.g. de Haan 2010; Wiek et al. 2011; Rieckmann 2012).

The CDIO Syllabus aims to set consistent and generalizable goals for undergraduate engineering education addressing the conceiving-designing-implementing-operating (CDIO) context. The first version of the Syllabus, formulated in 2001, showed limited explicit attention to sustainability and sustainable development (Crawley 2001). In 2011, the Syllabus was reviewed and updated into Version 2.0 (Crawley et al. 2011). The review was based on comparison with the UNESCO Four Pillars of Learning (Delores 1996), different national accreditation and evaluation standards, and other forms of input received over the decade since the Syllabus was originally written. The major focus of the review was the formulation of two additional Syllabus sections concerning leadership (4.7) and entrepreneurship (4.8). With reference to Knutson-Wedel et al. (2008), it was concluded that while the Syllabus can support the development of engineering education to address sustainability, the visibility of the concept of sustainability could be strengthened. This resulted in the addition of terms such as environmental, sustainability, sustainable, and safe, mainly in section 4 of the Syllabus where also a new sub-section 4.1.7 *Sustainability and the Need for Sustainable* Development was added. Similar small modifications were also made concerning innovation, invention, internationalization and mobility.

The prospect of further developing the CDIO Syllabus and Standards in the context of the Sustainable Development Goals is now being considered in a joint effort by the Nordic Five Tech Universities (Aalto University, Chalmers University of Technology, Technical University of Denmark, KTH Royal Institute of Technology, and Norwegian University of Science and Technology). As part of this endeavour, the objective of this paper is to evaluate to what extent the current version of the CDIO Syllabus reflects the key competencies for sustainability outlined in UNESCO (2017). The aim is to contribute to the bridging of the two domains *Engineering Education* and *Education for Sustainable Development* (ESD) and to the development of the CDIO Syllabus for maintaining its relevance in a changing world. A parallel paper by Malmqvist et al. (2019) considers related revisions of the CDIO Standards.

CDIO SYLLABUS AND STANDARDS

The starting point of the CDIO Initiative was to consider what knowledge, skills, and attitudes that engineering students should learn to prepare for engineering practice. The resulting document was called the *CDIO Syllabus* (Crawley, 2001). It is structured in four sections according to Figure 1: The first is a placeholder for the subject knowledge relevant for a particular educational programme, the second section lists personal and professional skills, while the third contains interpersonal skills. The fourth overarching section contains the ability to conceive, design, implement and operate products, processes, and systems, in the enterprise and societal context – or what could be called the CDIO shorthand for engineering competencies. Since the CDIO Syllabus is a very extensive set of goals, it must be emphasised that it is intended to be comprehensive but not prescriptive; no program could be expected to address all topics.

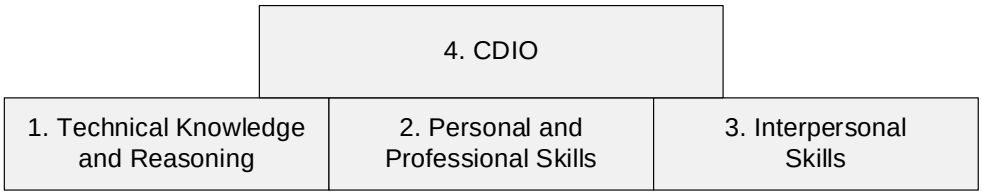

Figure 1. The four sections of the CDIO Syllabus (Crawley 2001).

It is not the CDIO Syllabus that defines the CDIO approach. Instead, the working definition is expressed in the CDIO Standards, formulated in 2004 to *define the distinguishing features of a CDIO program, serve as guidelines for educational program reform and evaluation, create benchmarks and goals with worldwide application, and provide a framework for continuous improvement* (CDIO 2004). Simply put, if the CDIO Syllabus defines what students should learn, the CDIO Standards are a set of aligned strategies for developing programs to address these learning goals. They focus on program aims (Standard 1), curriculum development (Standards 2, 3, 4), engineering projects and workspaces (Standards 5, 6), teaching and learning methods (Standards 7, 8), faculty development (Standards 9, 10), and assessment and evaluation (Standards 11, 12). The structure of the Syllabus can be clearly recognised when it is stated in the Standards that a program should set *specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders* (Standard 2). Hence, the main aim of the CDIO Syllabus is to be an instrument to guide the formulation of intended learning outcomes for a specific program, making priorities based on a particular context, conditions, ambitions, and stakeholder needs. As a comprehensive framework, it has been used for defining, analysing or comparing learning objectives in curriculum development – on program or course level, as well as in national and international quality assurance schemes.

KEY COMPETENCIES FOR SUSTAINABILITY

The consideration and implementation of *competencies* in educational systems have been an integral part of the shift from input-oriented knowledge-based educations to outcome-oriented competence-based educations, driven by the CDIO initiative, the Bologna process, and similar activities around the world. Such a shift builds on the idea that education should not only aim to provide knowledge in itself, but also foster the development of competencies as an interplay between knowledge, skills, and attitudes among the learners.

Key competencies for sustainability are competencies that, within the Education for Sustainable Development (ESD) domain, are considered necessary for all learners to cope with the increasingly diverse and interconnected world and to enable them to contribute to the urgently needed transformations towards a sustainable society. For example, the OECD DeSeCo project (OECD 2005) resulted in the definition of a set of nine key competencies. de Haan (2010) presented a set of twelve competencies subsumed under the term *Gestaltungskompetenz*, noting that those possessing these competencies *can help, through active participation, to modify and shape the future of the society, and to guide social, economic, technological and ecological changes along the lines of sustainable development*. Wiek et al. (2011) performed an extensive literature review, identifying various definitions of competencies related to sustainability, which were then clustered into a compiled set of five key competencies for sustainability. Here, critical thinking and basic communication skills were not included with the motivation that they should be considered as general competencies rather than key competencies. Rieckmann (2012) performed an empirical study among experts on higher education for sustainable development in a number of countries in Europe and South America, identifying a set of twelve key competencies, where critical thinking, systemic thinking and handling of complexity, and anticipatory thinking, were concluded to be the most important.

The key competencies in the above mentioned references have significant overlaps but also some differences, with several other definitions found in the literature as well. Hence, there is no general consensus on the specific definitions of key competencies for sustainability and the concept is still under development (e.g. Shephard et al. 2018). Some sort of convergence can, however, be seen, where key competencies are generally considered to represent cross-cutting, multifunctional, context- and domain-independent competencies.

In this paper, we use the eight key competencies for sustainability outlined by UNESCO (2017) as a reference when evaluating the CDIO Syllabus. Our motivation for choosing this particular set of competencies is two-fold: firstly, they connect directly to the SDGs in the UN 2030 Agenda, and secondly, they are well founded in other related literature (e.g. de Haan 2010; Wiek et al. 2011; Rieckmann 2012; OECD 2005) and can thereby be considered as a compilation of these. The UNESCO key competencies are here reproduced in Table 1, with each competency defined, or rather exemplified, in terms of a number of abilities according to UNESCO (2017). It should be noted that the UNESCO descriptions of the different competencies in Table 1 are rather limited, not least for the strategic competency, and that our analysis thereby will contain corresponding limitations.

Table 1. The eight key competencies for sustainability in UNESCO (2017).

Competency	Ability to…
1. Systems thinking competency	– recognize and understand relationships; – analyse complex systems; – think of how systems are embedded within different domains and different scales; – deal with uncertainty.
2. Anticipatory competency	– understand and evaluate multiple futures – possible, probable and desirable; – create one's own visions for the future; – apply the precautionary principle; – assess the consequences of actions; – deal with risks and changes.
3. Normative competency	– understand and reflect on the norms and values that underlie one's actions; – negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions.
4. Strategic competency	– collectively develop and implement innovative actions that further sustainability at the local level and further afield.
5. Collaboration competency	– learn from others; – understand and respect the needs, perspectives and actions of others (empathy); – understand, relate to and be sensitive to others (empathic leadership); – deal with conflicts in a group; – facilitate collaborative and participatory problem solving.
6. Critical thinking competency	– question norms, practices and opinions; – reflect on own one's values, perceptions and actions; – take a position in the sustainability discourse.
7. Self-awareness competency	– reflect on one's own role in the local community and (global) society; – continually evaluate and further motivate one's actions; – deal with one's feelings and desires.
8. Integrated problem-solving competency	– apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive and equitable solution options that promote sustainable development, integrating the abovementioned competences.

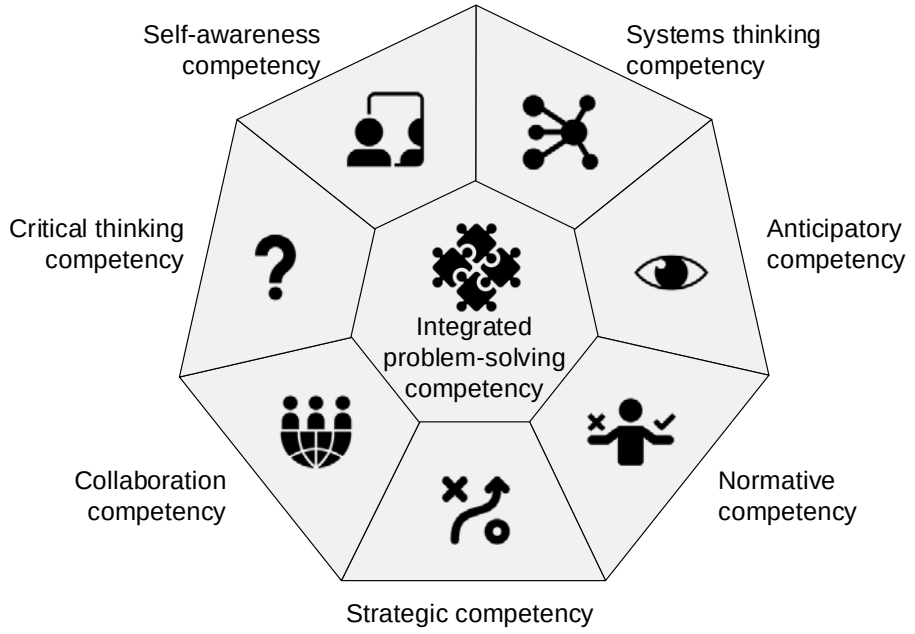

Figure 2. Our schematic illustration of the UNESCO key competencies framework.

METHOD

The objective of this paper is to evaluate to what extent the UNESCO key competencies for sustainability are reflected in the current version of the CDIO Syllabus as basis for further revision of the Syllabus. The evaluation is performed in two steps.

The first step is an analysis identifying topics, terms and concepts in the CDIO Syllabus that correspond to the different abilities of the UNESCO key competencies (as in Table 1). We use the current CDIO Syllabus version 2.0 (see Appendix B in Crawley et al. 2011) including sub-titles and explanatory keywords under the X.X.X level. The identified mapping is categorized on two levels: either i) explicit or otherwise strong mapping or ii) implicit or partial mapping.

Since the Syllabus section 1 is a placeholder for the subject knowledge relevant for a particular education programme, this mapping analysis only considers Syllabus sections 2-4. Further, it has become obvious through the process of this analysis that the 8th UNESCO key competency, *integrated problem-solving*, has a different character and role than the other competencies. As seen in Table 1, UNESCO defines this 8th competency as integrating the other seven key competencies. Similarly, Wiek et al. (2011) describe the incorporation of some of the key competencies in an integrated problem solving framework. Based on these observations we are here only addressing competencies 1-7 in the first step of the analysis, leaving *integrated problem-solving* for consideration in the second step.

The second step of the evaluation is a qualitative discussion where areas of strong mapping are highlighted and aspects that could be better visualized or strengthened in or added to, the Syllabus are identified. Differences in definitions of various concepts between the CDIO Syllabus and the UNESCO key competencies and the overall relation between the two frameworks are discussed.

The different key competencies have here been analysed by different working groups consisting of three to four of the co-authors of this paper representing different universities, disciplines and experiences. Several video conference discussions have provided further negotiation of our interpretation of the differences, providing a broad view and more valid understanding of the Syllabus and the key competencies. The analysis has hence been an interpretive process guided by conceptual reasoning and discussions between colleagues.

MAPPING

Overview

An overview of the identified mapping between the CDIO Syllabus and the UNESCO key competencies 1-7 is given in Table 2. Here dark coloured fields indicate explicit or otherwise strong mapping whereas light coloured fields indicate implicit or partial mapping. Fields marked with an asterisk indicates where we identified the potential for development. More details about the mapping analysis are provided in the appendix.

Strong mappings with basically all key competencies are identified for the Syllabus section 4.1 *External, Societal and Environmental Context*. This could be expected, not least since this is the section that was most updated regarding sustainability in the Syllabus 2.0 revision (Crawley et al 2011). Considering the nature of the sustainability concepts and concerns it is also expected that strong mapping with several of the key competencies is identified for the Syllabus sections 2.4 *Attitudes, Thought and Learning* and 2.5 *Ethics, Equity and Other Responsibilities*. On the other hand, rather weak mapping is identified between the key

competencies and the Syllabus sections 4.2 *Enterprise and Business Context*; 4.4 *Designing*; 4.5 *Implementing*; 4.7 *Leading Engineering Endeavors*; and 4.8 *Entrepreneurship*.

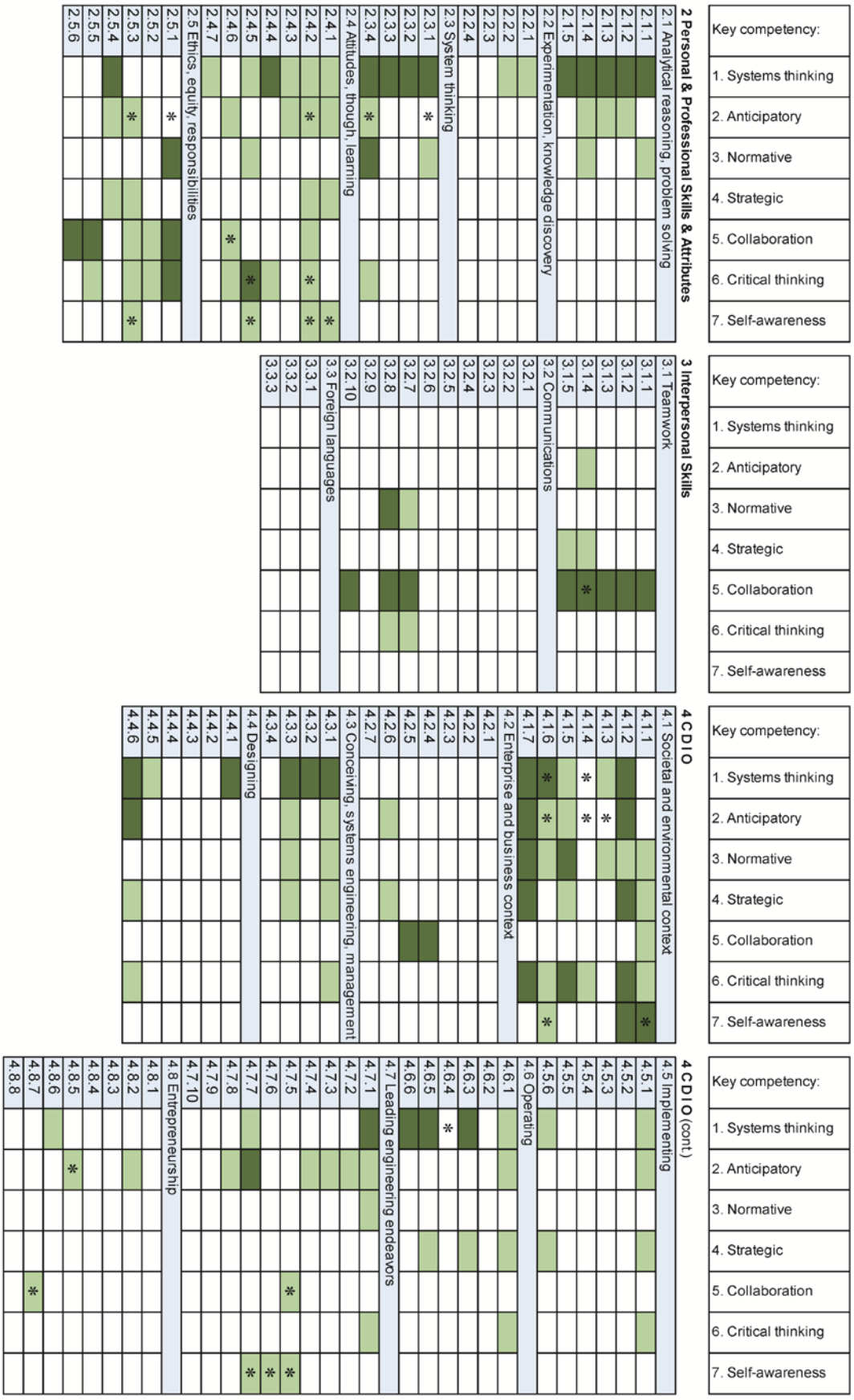

Table 2: Identified mapping between the CDIO Syllabus and the UNESCO key competencies 1-7. Dark colour=explicit/strong mapping; Light colour=implicit/partial mapping; Asterisk=potential/need for improvement.

Considering the individual key competencies, particularly strong mapping is found for the *systems thinking* competency basically all through Syllabus sections 2 and 4. Strong mapping is also found between the *collaboration competency* and the Syllabus section 3.1 *Teamwork* and quite strong also with 3.2 *Communication*. Quite some mapping is also found for the *anticipatory*, *normative*, and *critical thinking* competencies, whereas the mapping is weaker regarding the *strategic* and *self-awareness* competencies. Some further observations and opportunities for strengthening the CDIO Syllabus in relation to the UNESCO key competencies are discussed in the following sub-sections.

Systems thinking

The identified strong mapping with the *systems thinking* competency all through the Syllabus sections 2 and 4 and the fact that there is a particular Syllabus section dedicated for *System Thinking* (2.3), on one hand indicates that the CDIO notion of systems thinking is more narrowly defined than the UNESCO *systems thinking* competency. On the other hand, this reflects that *systems thinking* in a broader sense, also including practical "*systems doing*", is a core aspect of engineering. This is particularly strongly expressed in the Syllabus section 4. It can also be seen in the CDIO Standard 1, citing the *principle that product, process, and system lifecycle development and deployment – Conceiving, Designing, Implementing and Operating – are the context for engineering education*.

Temporal and spatial perspectives

The mapping analysis indicates opportunities for strengthening the CDIO Syllabus in relation to both the *systems thinking* and *anticipatory* key competencies regarding the consideration of different scales, in time as well as space, and future scenarios. Although CDIO certainly advocates broadening the view on technology and engineering, global perspectives, temporal perspectives, and future-oriented thinking are more narrowly expressed and could be emphasized for example in the Syllabus sections 2.3.1, 2.3.4, 2.5.1, 4.1.4 and 4.1.6. Abilities to apply the precautionary principle could be more emphasized, for example in 2.4.2 and 2.5.1. The Syllabus considers various visionary aspects, however, limited to one's own personal future and visions for products and enterprises. Abilities to create one's own vision for the future could be strengthened in 2.5.3.

Personal value-related aspects

The UNESCO description of *normative* competency emphasizes the understanding of norms and values that form the basis for one's actions, and the ability to reflect upon those. It also stresses the importance of the ability to negotiate trade-offs among complex conflicts of interest about values, principles and goals, where information may be uncertain or contradictory, i.e., to handle complex value added systems. The UNESCO description for *critical thinking* competency is closely related to *normative* competency and together they illustrate some of the overall differences between the CDIO Syllabus and the UNESCO key competencies. While there is a good match for *critical thinking* with respect to particulars, there are differences in the overall view of the nature of the competency. The CDIO Syllabus does not explicitly address norms based on specific interests, ideology or belief systems in the same way that the UNESCO description does. Instead, the CDIO Syllabus takes prevailing systems more as given, and emphasises familiarity with current practices (2.5.4). The focus is rather on understanding important contemporary values more generally (4.1.5). Both these abilities, addressing norms and reflecting, seem to be missing from the current CDIO Syllabus, and could be added under to section 2.4 *Attitudes, Thought and Learning*, with *question norms, practices and opinions* included into 2.4.5 or even meriting its own, new, goal (a suggested 2.4.8). The ability to reflect on one's own values, perceptions and actions could be added as part of 2.4.2 or 2.4.5.

It is clear that UNESCO links both *normative* competency and *critical thinking* to one's ability to take a position in the sustainability discourse (rather than, for example, plan and implement actions for sustainability, which is part of *strategic* competency). The UNESCO descriptions view both these competencies as personal, value-related competencies of questioning prevailing norms and practices, including the ability to reflect on one's own values and actions. There is a distinction between, on the one hand, norms and standards based on engineering practices and calculations, which should be challenged on scientific grounds, and, on the other hand, norms founded in specific interests, ideology or belief systems. The latter may form boundary conditions for which solutions or actions are acceptable in a given situation. An understanding of this distinction is central to the ability to negotiate trade-offs among conflicting interests. While the UNESCO description conflates the two aspects, the CDIO Syllabus could clarify the distinction by distinguishing between them, most profitably in the syllabus sections indicated above.

This difference can also be seen in relation to the *self-awareness* competency. The CDIO Syllabus seems to connect self-awareness mainly to the cognitive domain of learning and metacognition, while the UNESCO approach emphasizes self-reflection regarding one's own role, feelings and desires. The Syllabus could be strengthened in relation to the *self-awareness* competency by adding abilities to reflect also one's own role locally and globally, and the ability to recognize and deal with one's feelings and desires in sections 2.4.5, 4.1.1 and 4.1.6. The ability to recognize and deal with one's feelings and desires, and also the ability to understand how they influence one's behaviour, willingness, effectivity, flexibility and motivation, could be added to 2.4.1, 2.4.2, and 4.7.5. The ability to continually evaluate and further motivate one's actions could be emphasized more in 2.5.3, 4.7.6, and 4.7.5. Finally, the collective abilities for self-awareness competency could be included in 4.7.7. With these developments, the CDIO Syllabus would actually go beyond the UNESCO key competency also including self-awareness for others and not just for one self.

Learning from others, participatory and empathic approaches

Collaboration is an important part of the CDIO framework and the Syllabus matches the collaborative competency to a very high degree. We found that the CDIO Syllabus focus to a high degree on teamwork primarily among engineers, and less so on collaboration across disciplines. The latter aspect is consistent with our findings with respect to *normative* competency and *critical thinking*, where we noted an absence in the CDIO Syllabus of an explicit mention of how to deal with values. Also, we found that the Syllabus could better emphasise the ability to learn from others (2.4.6), the need to consider collaborative and participatory problem-solving (3.1.4), and empathic leadership (4.7.5 or 4.8.7). At the same time, the CDIO Syllabus goes beyond the UNESCO competency when it comes to encouraging and inspiring others, and supporting their learning.

A note on the structures of the frameworks

This mapping process helped us see interconnections and dimensional qualities, making it clear that neither framework is a straight list. In the UNESCO framework, *integrated problem solving* integrates the other seven competencies. We illustrate this by placing it in the centre of the heptagon in Figure 2. Similarly, the CDIO Syllabus also has dimensions, as shown in Figure 1. In the CDIO framework it is *engineering* – or conceiving, designing, implementing and operating – that is the overarching and integrating competency, with 4.1 and 4.2 representing the context. If the CDIO Syllabus is further updated with respect to sustainability, as outlined in this paper, it could show a way for *practical* integrated problem-solving, well aligned with the UNESCO key competencies framework.

TOWARDS CDIO SYLLABUS 3.0

This study has shown that the current version of the CDIO Syllabus is already to quite some extent aligned with the UNESCO key competencies for sustainability. This can partly be explained by the previous enhancements regarding sustainability in the Syllabus 2.0 revision (Crawley et al. 2011) but even more by the strong emphasis on generic engineering skills as one of the core aspects of the CDIO Syllabus and the obvious correspondence between those skills and some of the key competencies such as collaboration, systems thinking and problem solving. Still, several opportunities (not to say needs) for strengthening the Syllabus in relation to the key competencies have been identified.

Just like we reason with regards to the generic engineering skills, sustainable development and therewith related competencies should not be treated as an add-on in isolated courses, but instead, be thoroughly integrated into education program curricula in line with the CDIO philosophy of integrated learning. Enhanced integration of sustainable development will contribute to improving the relevance and future compliance of engineering educations and could also contribute to students' and teachers' motivation. This study has shown that the UNESCO key competencies, and the underlying research literature, are useful instruments for scrutinizing and updating the CDIO Syllabus. In the other way around, implementations in the Engineering Education domain could also contribute to developing further understanding of the key competencies within the Education for Sustainable Development domain. Also regarding pedagogical approaches and learning activities there are opportunities for knowledge and methods transfer between these two educational domains (see for instance chapter 2 in UNESCO (2017) and Lozano et al. (2017) in relation to the CDIO Standards 7 and 8).

We propose that the results from this study are used as a basis for a structured process for updating the CDIO Syllabus into a version 3.0. As demonstrated and discussed in this paper such updating would partly be about adding words and expressions and partly about broadening and deepening the current conceptions of generic skills for better alignment with the key competencies.

Somewhat outside the scope of this paper, but still worth stating in the context of Syllabus updating, is the opportunity (not to say need) to add generic sustainability knowledge as an element in the Syllabus section 1. This section was deliberately excluded from our mapping analysis since it is mainly a placeholder for fundamental scientific and engineering knowledge that has to be defined for each education programme. However, as highlighted by Knutson-Wedel et al. (2008), in addition to domain-specific sustainability knowledge to be considered for each education program, there also exists a common domain- and program-independent core of sustainability knowledge that is crucial for all engineers and therefore would be motivated to include in section 1. This, for example, concerns knowledge of fundamental sustainability concepts, international policies, and possibilities and limitations of the use of different natural resources from a sustainability point of view.

Neither the CDIO Syllabus nor the UNESCO key competencies are prescriptive and they only address what students should learn. Enhanced integration of sustainable development in the CDIO framework will, therefore, require parallel revisions of the CDIO Syllabus and the CDIO Standards. Further background to and proposals of revisions of the CDIO Standards is considered in the parallel paper by Malmqvist et al. (2019).

With these changes, we suggest that the CDIO community can adopt the aim to educate students to *conceive, design, implement and operate complex value-added engineering products, processes, systems and services* ***for a sustainable society***.

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BIOGRAPHICAL INFORMATION

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APPENDIX – MAPPING ANALYSIS DETAILS

Systems thinking competency

Systems thinking is a central concept within the CDIO framework and in the CDIO Syllabus we find a very strong match with the Systems thinking competency. It is covered by the sections *2.1 Analytic Reasoning and Problem Solving, 2.3 System Thinking* and *4.1 External, Societal and Environmental Context*. The four abilities that are explicitly mentioned (see Table 1; underlined below) correspond to the following items in the CDIO Syllabus: The ability to recognize and understand relationships is present throughout *2.3 System Thinking*, most directly in *2.3.2 emergence and interaction*s which specifies *abstractions necessary to define and model the entities or elements of the system*, and the *important relationships, interactions and interfaces among elements*. The ability to analyse complex systems is fully addressed by a combination of *2.1 Analytic Reasoning and Problem Solving* and *2.3 System Thinking*. The former lists *problem identification and formulation* (2.1.1), *modeling* (2.1.2), *estimations* (2.1.3), *analysis with uncertainty* (2.1.4) and *recommendations* (2.1.5), while the latter lists *thinking holistically* (2.3.1), *prioritization and focus* (2.3.3), and *trade-offs, judgment and balance* (2.3.4). Arguably, this requires *creative thinking* (2.4.3), with keywords such as *conceptualization, abstraction, synthesis and generalization*, as well as *critical thinking* (2.4.4) with *purpose and statement of the problem or issue, logical arguments, supporting evidence, points of view and theories, conclusions and implications*. The ability to think of how systems are embedded within different domains and different scales matches *thinking holistically* (2.3.1), explicitly mentioning *transdisciplinary approaches that ensure the system is understood from all relevant perspectives*, and the *societal, enterprise and technical context of the system.* Another relevant aspect is *willingness to consider and embrace various viewpoints* (2.4.2). Also *4.1 External, Societal and Environmental Context* is relevant, as seen in phrases such as the *impact of engineering on the environmental, social, knowledge and economic systems in modern culture* (4.1.2) *historical and cultural context* (4.1.4), *contemporary issues and values* (4.1.5), *global perspective* (4.1.6) and *sustainability* (4.1.7). The ability to deal with uncertainty is addressed in *2.1 Analytic Reasoning and Problem Solving*, for instance in relation to estimations and assumptions in *problem formulation* (2.1.1) and *modeling* (2.1.2), and also in *analysis with uncertainty* (2.1.4) An associated attitudinal component is the *willingness to make decisions in the face of uncertainty* (2.4.1).

In the comparison, some aspects emerge that could be expressed more explicitly in the Syllabus. There are cases where the heading (on x.x.x level) is highly appropriate, but the sub-items listed suggest a narrower scope or understanding of a topic. For instance:

1) In *the historical and cultural context* (4.1.4), we miss items such as “Interpreting problems and issues in a historical and cultural context” and “Applying a historical and cultural perspective in creating and evaluating potential solutions”.
2) In *developing a global perspective* (4.1.6), we suggest adding “Assessing the consequences of technical systems in a global perspective”
3) While *system improvement and evolution* (4.6.4) is highly relevant, the given examples seemingly refer to commercial handling of product generations. A more general bullet could be added, such as “Continuous improvement and evolution based on observations of system performance, changing needs or new opportunities”.

Anticipatory competency

The ability to create one’s own vision for the future is to some extent considered under *proactive vision and intention in life* (2.5.3) and *leadership and entrepreneurship* (4.7.2, 4.7.3, 4.7.7). Future perspectives are further considered in terms of: *needs and opportunities* in general (2.4.1, 4.7.1, 4.8.2) and particularly regarding sustainability (4.1.7, 4.3.1); *goals and trade-offs* (2.3.4, 4.3.3); and various *life-cycle considerations* (4.3.3, 4.4.6). Life-cycle

considerations can also be related to the ability to assess the consequences of actions, which is also addressed in terms of *new technology development and assessment* (4.2.6), *implications* and *impact* of engineering and technology on social, environmental, and economic systems (2.5.4, 4.1.2, 4.8.5), and *modeling* (2.1.2, 2.1.3). The ability to deal with risks and changes is explicitly considered in the contexts of *2.1 Analytical Reasoning and Problem Solving* and *2.4 Attitudes, Thought and Learning* in terms of *analysis with uncertainty*, *probabilistic and statistical models*, *cost-benefit and risk analysis* (2.1.4, 2.4.1), and also in the context of *leadership and entrepreneurship* (4.7.7). The ability to understand and evaluate multiple futures – possible, probable and desirable and to apply the precautionary principle are to some extent considered in 2.2.3 and 4.7.7 and by the above identified vision and future related elements. Anticipatory competency could also be considered as implicitly included in all considerations of *sustainability* related to conceiving, designing, implementing and operating (4.1.7, 4.4.6, 4.5.1). There could however be options for strengthening these formulations in the syllabus, for example by adding 'sustainable' (e.g. in 4.8.5) and by emphasizing societal needs and how legal and political systems do and could regulate and influence engineering in a sustainable direction (in 4.1.3).

Some aspects that could be expressed more explicitly in the Syllabus are the importance of different time scales and the abilities to evaluate different future scenarios. These could be emphasized for example in *thinking holistically* (2.3.1) and in *trade-offs, judgment and balance in resolution* (2.3.4). Further, *historical and cultural context* (4.1.4) and *developing a global perspective* (4.1.6), could be complemented to also include influences on future conditions and opportunities. The Syllabus considers various visionary aspects, however, limited to one's own personal future and visions for products and enterprises. Abilities to "create one's own vision for the future" could be added in (2.5.3). Abilities to apply the precautionary principle could be more emphasized, for example in 2.4.2 and 2.5.1.

Normative competency

The ability to understand and reflect on the norms and values that underlie one's actions is explicitly addressed in *ethics, integrity and social responsibility* (2.5.1), which is about ethical standards and principles, and the possibility of conflicts between ethical imperatives. With respect to sustainability it is further addressed in *contemporary issues and values* (4.1.5) which specifies the processes by which contemporary values are set, and in *sustainability and the need for sustainable development* (4.1.7). Other Syllabus items specify aspects that implicitly address and support the same ability, such as *problem identification and formulation* (2.1.1) that addresses assumptions and sources of bias, *thinking holistically* (2.3.1) that stresses the societal, enterprise and technical context of the system, and *self-awareness, metacognition and knowledge integration* (2.4.5). Other relevant sections are *roles and responsibilities of the engineers* (4.1.1), *the impact of engineering on society and the environment* (4.1.2), *developing a global perspective* (4.1.6), together with *understanding needs and setting goals* (4.3.1). The ability to negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions corresponds to *trade-offs, judgment and balance in resolution* (2.3.4), and *negotiation, compromise and conflict resolution* (3.2.8). The ability is also implicitly addressed and supported through *analysis with uncertainty* (2.1.4), *inquiry, listening and dialog* (3.2.7) addressing aspects supporting negotiation skills, and *system engineering, modelling and interfaces* (4.3.3) where trade-offs and iteration are identified as desired aspects. Finally, the need to identify all aspects of a problem at hand, including underlying paradoxes is addressed in *identifying the issue, problem or paradox* (4.7.1).

Strategic competency

The strategic competency is by UNESCO described as the ability to collectively develop and implement innovative actions that further sustainability at the local level and further afield. The CDIO syllabus reflects the components of this ability in several places. The collective dimension is emphasised in various ways in *team leadership* (3.1.4) and *technical and multidisciplinary teaming* (3.1.5). It could further be argued that development and implementation of innovative actions is done through the familiar process of 4.3 - 4.6, *Conceiving, Designing, Implementing and Operating*. Dimensions of furthering sustainability at the local level and further afield is covered in different parts of the syllabus including the *impact of engineering on society and the environment* (4.1.2), where the impact of engineering on the environmental, social, knowledge and economic systems in modern culture is addressed. The need to apply sustainability principles in engineering endeavours is part of *sustainability and the need for sustainable development* (4.1.7). Also, the awareness of the the responsibilities of engineers to society and a sustainable future is identified in *roles and responsibility of engineers* (4.1.1). *Understanding needs and setting goals* (4.3.1) addresses environmental needs as well as ethical, social, environmental, legal and regulatory influences, which must be furthering sustainability. Finally, *design for sustainability, safety, aesthetics, operability and other objectives* (4.4.6) and *designing a sustainable implementation process* (4.5.1) addresses important aspects of the furthering dimension. To conclude, we find a good match in the CDIO syllabus for every element of the strategic competency. We still hold that the strategic competency, as described by UNESCO, could be made to stand out more clearly in the syllabus.

Collaboration competency

The collaborative competency is directly addressed, and mostly covered, by the sections *2.5 Ethics, Equity and other Responsibilities, 3.1 Teamwork* and *3.2 Communications*. The ability to learn from others is somewhat present in *perseverance, urgency and will to deliver, resourcefulness and flexibility* (2.4.2), *lifelong learning and educating* (2.4.6)*, team growth and evolution* (3.1.3), *inquiry, listening and dialog* (3.2.7) and *building and leading an organization and extended organization* (4.7.5). The ability to understand and respect the need, perspectives and actions of others (empathy) is addressed by a combination of *2.5 Ethics, Equity and other Responsibilities and 3.1 Teamwork*. It directly matches *ethics, integrity and social responsibility* (2.5.1)*, equity and diversity* (2.5.5)*, trust and loyalty* (2.5.6)*, forming effective teams* (3.1.1)*,* and *establishing diverse connections and networking* (3.2.10). It is furthermore to some extent included in *professional behavior* (2.5.2)*, roles and responsibility of engineers* (4.1.1), *sustainability and the need for sustainable development* (4.1.7)*, working in organizations* (4.2.4), *working in international organizations* (4.2.5). The ability to understand, relate to and be sensitive to others (empathic leadership) matches *trust and loyalty* (2.5.6), *working in organizations* (4.2.4) *and working in international organizations* (4.2.5). The ability to deal with conflicts in a group is highly present in *team operation with a focus on conflict mediation, negotiation and resolution* (3.1.2), and in *negotiation, compromise and conflict resolution* (3.2.8)*.* Finally, the ability to facilitate collaborative and participatory problem solving is present throughout *3.1 Teamwork*, for instance in *forming effective teams* (3.1.1), *team operation* (3.1.2)*, team growth and evolution* (3.1.3), *team leadership* (3.1.4) and *technical and multidisciplinary teaming* (3.1.5).

When considering the extent to which the CDIO Syllabus addresses the collaborative competency, we find some parts are missing in the syllabus. There is far more emphasis on communicating to others, than on learning from others. There is also a lack of empathic leadership. We, therefore, propose adding the following three abilities to the Syllabus:
1) “Facilitate collaborative and participatory problem-solving” into *team leadership* (3.1.4),
2) “Ability to learn from others” into *lifelong learning and education* (2.4.6), and

3) “Developing empathic leadership” into *building and leading an organization and extended organization* (4.7.5) or into *building the team and initiating engineering processes* (4.8.7).

On the other hand, the Syllabus emphasizes another point of view that is absent from the UNESCO definition: how one is able to affect and encourage others. To mention but a few examples, the ability to *enable learning in others* can be found in *lifelong learning and educating* (2.4.6), the commitment to *help others* is mentioned in *2.5 Ethics, Equity and other Responsibilities*, and *inspiring others* is part of *proactive vision and intention in life* (2.5.3).

Critical thinking competency

Critical thinking (as described by UNESCO) is visible in CDIO Syllabus particularly in relation to *self-awareness, metacognition and knowledge integration* (2.4.5), *ethics, integrity and social responsibility* (2.5.1) and *contemporary issues and values* (4.1.5) that all emphasise personal abilities for responsible, value-based actions and reflective thinking, and therefore link directly to the first two abilities of UNESCO’s definition, question norms, practices and opinions and reflect on own one’s values, perceptions and actions. These abilities are also to lesser extent visible in a number of other places, including *2.4 Attitudes, Thought and Learning* (particularly 2.4.4 and 2.4.6), *2.5 Ethics, Equity and other Responsibilities* (particularly 2.5.2, 2.5.3 and 2.5.5) and *3.2 Communications* (particularly 3.2.7 and 3.2.8). The ability to take a position in the sustainability discourse) is most directly visible as *the impact of engineering on society and the environment* (4.1.2) and *sustainability and the need for sustainable development* (4.1.7). This ability is naturally related also to *4.1 External, Societal, and Environmental Context* (especially sub-goals 4.1.1, 4.1.4, 4.1.5 and 4.1.6). It can also be seen to match other Syllabus items related to sustainability (including 4.3.1, 4.4.6, 4.6.1 and 4.7.1).

Self-awareness competency

Self-awareness is explicit in the heading *self-awareness, metacognition and knowledge integration* (2.4.5). This ability to reflect on one’s own role in the local community and (global) society is addressed in the Syllabus by: *sense of responsibility for outcomes* (in 2.4.2), *a personal vision for one’s future* and *considering one’s contributions to society* (in 2.5.3), *roles and responsibility of engineers* (4.1.1) and *the Impact of engineering on society and the environment* (4.1.2). The ability to continually evaluate and further motivate one’s actions can be recognized in: *decisions, based on the information at hand* and *the potential benefits and risks of an action or decision* (both in 2.4.1), and in *sense of responsibility for outcomes* and *adaptation to change* (both in 2.4.2). The ability to deal with one’s feelings and desires is to some extent addressed by *determination to accomplish objectives, a readiness, willingness and ability to work independently, a willingness to work with others, and to consider and embrace various viewpoints, the balance between personal and professional life, self-confidence, courage and enthusiasm*, and *an acceptance of feedback, criticism and willingness to reflect and respond* (all in 2.4.2).

The content in section *self-awareness, metacognition and knowledge integration* (2.4.5) could be made more relevant for the self-awareness competency by adding points that reflect also one’s own role locally and globally, and the ability to recognize and deal with one’s feelings and desires. One’s own role could be further strengthened also in the *roles and responsibility of engineers* (4.1.1) and *developing a global perspective* (4.1.6). The ability to recognize and deal with one’s feelings and desires, and also the ability to understand how they influence one’s behavior, willingness, effectivity, flexibility and motivation, could be added to *Initiative and willingness to make decisions in the face of uncertainty* (2.4.1), *perseverance, urgency and will to deliver, resourcefulness and flexibility* (2.4.2), and *building and leading an organization and extended organization*) (4.7.5). The ability to continually evaluate and further motivate one’s actions could be emphasized more in *proactive vision and intention in life* (2.5.3) as well as in *managing a project and its human resources* (4.7.6), and could be strengthened

even more by adding *continuous self-evaluation in relation to teamwork and leadership* (to 4.7.5). Finally, the collective abilities for self-awareness competency, could be included in *exercising project/solution judgment and critical reasoning* (4.7.7).

The suggestions above to add self-awareness competency associated to leadership (in 4.7) would imply that the Syllabus would go beyond the UNESCO key competency, since this also includes self-awareness for others and not just for one self.

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