The CDIO Syllabus 3.0 - An Updated Statement of Goals

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THE CDIO SYLLABUS 3.0 - AN UPDATED STATEMENT OF GOALS

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ABSTRACT

The CDIO Initiative is going through a process of reconsidering and updating the CDIO approach for engineering education development. Previous work resulted in substantial updates of the twelve CDIO standards and the introduction of "optional" CDIO standards. This paper reports on a similar review and update of the CDIO Syllabus to version 3.0. It has been developed by a working group consisting of four sub-groups and iterated and refined guided by feedback from the whole CDIO community. There are mainly three external drivers that motivate the changes: sustainability, digitalization, and acceleration. There is also an internal driver in the form of lessons learned within the CDIO community, from using the Syllabus in curriculum and course development. Approximately 70 updates are proposed, amongst them three additions on the X.X level, namely 1.4 *Knowledge of Social Sciences and Humanities*, 3.1 *Teamwork and Collaboration*, and 5.3 *Research*.

KEYWORDS

CDIO Syllabus, Sustainability, Digitalization, Acceleration, Standards 1-12, Optional standards

INTRODUCTION

During the past few years, the CDIO Initiative has gone through a process for reconsidering and updating the CDIO approach for engineering education development. The first stages of this work consisted of a substantial updating of the original twelve, now called "core", CDIO standards (Malmqvist et al., 2020a) as well as the introduction of a first set of four so-called "optional" CDIO standards that codify additional educational good practises that have been developed within the CDIO community (Malmqvist et al., 2020b). What remains now is to establish a new version of the CDIO Syllabus.

The starting point of the CDIO Initiative was to consider what knowledge, skills, and attitudes engineering students needed to learn to prepare for engineering practice. The aim was to create a clear, complete, and consistent set of goals for first-degree engineering education. The resulting document was called the CDIO Syllabus, a list of topics that indicate desirable competences of graduating engineers. This makes the Syllabus a reference framework that can be used to select goals for curricula and courses. The first version of the CDIO Syllabus was published in 2001 (Crawley, 2001).

The Syllabus has been thoroughly reviewed and updated once before, resulting in version 2.0 (Crawley et al., 2011). The 2011 review was based on comparison with the UNESCO Four Pillars of Learning (Delors, 1996), various national accreditation and evaluation standards, and other forms of input received over the decade since the Syllabus was originally formulated. A major result was the formulation of two additional sections concerning leadership (4.7) and entrepreneurship (4.8). Minor updates were also made to address innovation, invention, internationalization, mobility, and sustainability, resulting in, for example, the added subsection *Sustainability and the Need for Sustainable Development* (4.1.7).

In the decade since the previous review, three change drivers in particular affect what competences are desired of graduating engineers. One change driver is the growing awareness and evidence of the impact of human activities on our planetary system and ecosystems and the urgent needs for societal transformations to ensure sustainable living conditions for ourselves and future generations (e.g., UN, 2015; IPCC, 2018; WWF, 2020). Another change driver is digitalization as a key technology enabling engineers to address novel problems and existing problems in more effective ways, which also brings along new risks to mitigate. The third change driver is the conception of the world as accelerating, rapidly changing, and increasingly complex which is embodied in narratives about Industry 4.0, Society 5.0, and the VUCA world (e.g., Kamp, 2020), requiring decision-makers to continually be ready to reconsider and adapts. In addition to these external driving forces, there is also within the international CDIO community extensive experience of the use and customization of the CDIO Syllabus. A fourth, internal change driver is thus to take into account the lessons learned from using the Syllabus in curriculum and course development.

This paper describes the review process and the proposed changes, resulting in the CDIO Syllabus 3.0.

THE CDIO SYLLABUS

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 was originally structured in the four sections 1-4 according to Figure 1. The first section is a placeholder for the fundamental knowledge relevant for a particular educational program, 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, systems, and, services in the enterprise and societal context – or what could be called the CDIO shorthand for engineering competencies. The sections contain two additional levels of detail, here referred to as the X.X and X.X.X levels, and an unnumbered list below the X.X.X level. The update of the Syllabus presented in this paper has implied extensive revisions and modifications on all levels, including, as indicated in Figure 1, the addition of a fifth "*Expansion*" section.

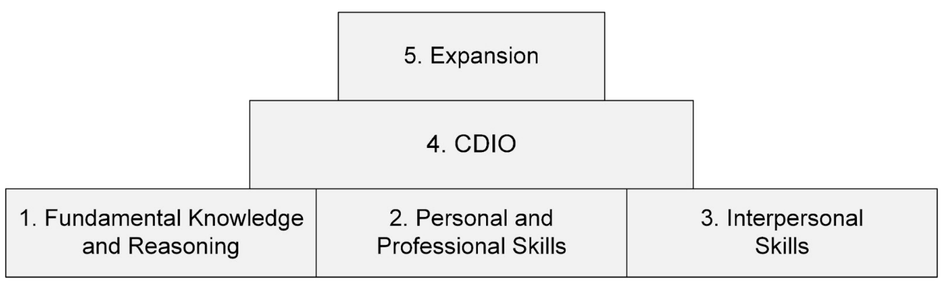

Figure 1. The four sections of the original CDIO Syllabus (Crawley, 2001) complemented with a fifth "Expansion" section in the updated CDIO Syllabus 3.0.

The recommended use of the CDIO Syllabus is as a source of inspiration or as a frame of reference, for instance when considering possible features in a program, comparing programs, or discussing the contributions of courses in a curriculum. Since the Syllabus is very extensive, it must be emphasized that it is intended to be comprehensive but *not prescriptive*. Hence, no program can be expected to address every topic. Formulating the goals for a specific program always implies a process of customization for the particular context, set of conditions and stakeholder needs.

To facilitate many different uses, as the ones mentioned above, the Syllabus is formulated in a hierarchical structure. To avoid being overwhelmed by the length and level of detail of the document, the recommendation is then to focus on the appropriate level. For instance, when discussing priorities in a curriculum, the second level (X.X) may well suffice. On the other hand, an instructor working on course development may choose to find inspiration in all the lower-level details (X.X.X and the accompanying topics), but should do so without feeling compelled to address each single topic.

UPDATING THE CDIO SYLLABUS

Overall Process

As described in the introduction, the updating of the Syllabus from the prevailing version 2.0 (Crawley et al., 2011) into a new version 3.0, has been motivated by the emergence of external change drivers and internal experiences within the CDIO community, categorized in the following four themes:

1. Sustainability
2. Digitalization
3. Acceleration
4. Experiences

A small initial working group was established in February 2021 with representatives from six European universities. The group was organized in four subgroups, responsible for each of the four themes. The subgroups had initial online meetings during February. The whole group gathered again for an online meeting in March for sharing of ideas and establishment of preliminary principles and processes for the updating, format of this paper, overall planning, and an online collaboration platform.

The working group was established in connection to the CDIO 2021 conference and more members were invited. For the subgroups 1-3 the updating was based on the identification and review of a broad spectrum of recent literature related to these three themes, whereas subgroup 4 reviewed all papers in the proceedings from the International CDIO Conferences for the previous three years. Competences and related topics that could enhance the Syllabus with regard to the four themes were identified and changes to the Syllabus were drafted. Inputs from the different members were discussed and negotiated, first within each subgroup and then by the whole working group, in an iterative process with several online meetings, to ensure validity and applicability.

In September 2021, a first public draft of the updated Syllabus was compiled and circulated to all CDIO member universities for review. The received feedback was thoroughly discussed and further processed at the CDIO International Working Meeting, held online during November 17-18 in successive sessions in three time zones. The working group, which had now been expanded with representatives from universities in Singapore, Russia, and Canada, continued to process through online collaboration, and compiled a final version of the updated Syllabus and finalized the draft version of this paper in January 2022. More details about the background and motivation and methods for revision and updating with regard to the respective themes are provided in the result section below.

RESULTING UPDATES

Overall

As presented in detail in the following subsections, revisions have been made with regard to all four themes in the Syllabus sections 2, 3, and 4. As indicated in the previous section, only a few updates have been made on the X, X.X, and X.X.X levels, whereas most updates are found in the lists under the X.X.X levels.

The former sections 4.7 *Leading Engineering Endeavors* and 4.8 *Engineering Entrepreneurship*, that were added in the previous Syllabus revision (Crawley et al., 2011), have been renumbered to 5.1 and 5.2 and have, together with a newly developed section 5.3 Research, been included in a new Syllabus section 5. As pictured in Figure 1, this new section 5 is denoted "Expansion" in accordance with the notion used in Crawley et al. (2011). The rationale for this new section is that, in contrast to sections 1-4 that relate to competences needed by all graduates, the expansions in section 5 are only relevant to certain subsets of students, since not all will undertake research endeavours, aim at leadership positions, or become entrepreneurs.

Revisions made with regard to the themes Sustainability, Digitalization, Acceleration, and Experiences, have called for an enhancement of the roles of social sciences and the humanities in engineering education. As a consequence, the title of Section 1 has been updated to now read "Fundamental knowledge and reasoning", where "Fundamental" has replaced the former "Disciplinary", while a section has been added 1.4 Knowledge of social sciences and humanities.

In this text, "Category" refers to level 1 (X) changes, "Subcategory" to the levels 2 and 3 (X.X and X.X.X). A "Topic" is an unnumbered item (typically level 4) and subtopics are unnumbered items corresponding to level 5. Additions or deletions of items make reference to the numbering and level. The term "Aspect changes" is used for changes that imply modifications of a category/subcategory/topic definition but not additions/removals.

Sustainability

Background and motivation

One of the major change drivers motivating and guiding the revision of the CDIO framework, is the recognition that engineering and engineering education plays critical roles in the societal transformations that are needed for ensuring a healthy planet and sustainable living conditions for ourselves and future generations (e.g., Enelund et al., 2013; UN, 2015; IPCC, 2018; WWF, 2020; UNESCO, 2021).

The CDIO Standards have been updated accordingly (Malmqvist et al., 2020a,b) and the overarching CDIO rationale in Standard 1 now reads "*Adoption of the principle that sustainable product, process, system, and service lifecycle development and deployment – Conceiving, Designing, Implementing and Operating – are the context for engineering education*". In Standard 1 it is also stated that "*The consideration of environmental, social, and economic sustainability is an integral part throughout the lifecycle*". Sustainability and sustainable development are further explicitly reflected in Standards 2, 3, 7, 9, and 11, and hereby permeate the whole set of core Standards. The importance of and opportunities with engineering education for sustainable development are further emphasized by the new optional CDIO Standard for Sustainable Development (Malmqvist et al., 2020b).

Sustainability was also one of several targets in the previous revision of the CDIO Syllabus (Crawley et al. 2011), resulting in the addition of terms such as environmental and sustainability, mainly in section 4, and a new subsection 4.1.7 *Sustainability and the Need for Sustainable Development*. Rosén et al. (2019) explored to what extent and how the key competencies for sustainability outlined in UNESCO (2017) are reflected in the Syllabus. It was concluded that the Syllabus was already to some extent aligned with the UNESCO competencies. Similarities were identified between the integrated problem-solving key competency in the UNESCO framework and the Conceive-Design-Implement-Operate competences in the CDIO framework as overarching and integrating competencies. However, needs and opportunities for enhancing the CDIO Syllabus with regard to sustainable development were also identified.

Method

In the here proposed update of the CDIO Syllabus, the needs and opportunities identified in Rosén et al. (2019) have been further refined and implemented. Rosén et al. (2019) however concluded that the UNESCO (2017) definitions of the key competencies are quite limited. The updates proposed here have therefore been further informed by key competency frameworks presented in EOP (2020), Lozano (2017), Wiek et al. (2011; 2016), also by the 2030 Agenda (UN, 2015), of course also by the CDIO Standards 3.0, and by principles and perspectives proposed by Becker et al. (2015), Choi & Pak (2006), EU (2018), Mathebula (2018), McDonough & Braungart (2002), Raworth (2017), and Rist (2019). Through individual working group members' analysis and several video conference discussions, the most essential elements to be included in an engineering education key competency base-line have been negotiated, and corresponding proposals for updating the CDIO Syllabus have been formulated. The initial stage of the Syllabus updating with regards to sustainability can hence be described as an interpretive process, informed by principles of Education for Sustainable Development (ESD), and guided by conceptual reasoning and discussions between colleagues.

Results

The urgent need for and systemic characteristics of societal transformations and the crucial role of engineers in sustainable development, have been taken as motivations for quite substantial updating of the CDIO Syllabus with regard to sustainability. The following are the major changes that are proposed in the [Appendix].

Section 2.3 *System thinking* has been enhanced from the previous narrow focus on technical systems to a more holistic perspective on technical systems' and human societies' embedment in, and dependency and impact on, the ecological and planetary systems. 2.4 *Attitudes, thought and learning* has been enhanced with regard to the self-awareness and critical-thinking key competencies for sustainability. 2.5 *Ethics, equity and other responsibilities* has been enhanced with regard to the self-awareness, normative, and anticipatory key competencies for sustainability.

In section 3, the competences previously outlined in section 3.1 *Teamwork* and its subsections 3.1.1-5 have been substantially elaborated and condensed into a new subsection 3.1.1 *Working in teams*. The term '*Collaboration*' has been introduced and included in the titles of section 3 and subsection 3.1 to complement the more instrumental competences related to 'teamwork' with a broader set of competences related to collaborations with broader and more heterogeneous groups of stakeholders which are outlined in the new subsections 3.1.2 *Multi-perspective collaboration* and 3.1.3 *Stakeholder engagement*. As a consequence of these changes, subsection 3.2.10 *Establishing Diverse Connections and Networking* has been moved and now constitutes subsection 3.1.4. *In* 3.2.7 *Inquiry, Listening and Dialog*, the aspect Body language and the silent voice has been added.

Section 4.1 has been retitled to *Societal and environmental context* (previously *External...context*) and enhanced with regard to historical, cultural, and global perspectives, and self-awareness, normative, anticipatory, and systems-thinking, key competencies for sustainability. A new section 4.1.6 *Visions of the future* has been added. Section 4.2 *Enterprise and business context*, has been enhanced to emphasize that technology should contribute to a sustainable development, and that indirect stakeholders must be considered and cared for. 4.3 *Conceiving, system engineering and management* has been enhanced to especially include strategic competency in the context of understanding needs and setting goals in a new subsection 4.3.1 *Understanding societal and planetary goals and constraints*. 4.4 *Designing* has been elaborated on what is meant by design for sustainability. In 4.6 *Operating* circularity has been added to lifecycle management, and the concept of values and costs has been broadened in subsection 4.6.5 which is renamed to *Disposal, end-of-life, and circularity*.

Further, section 5.1 *Leading engineering endeavors* has been enhanced with regard to the self-awareness key competency related to topics that lead to delivering on the vision.

As a consequence of the here proposed Syllabus updates and the already updated CDIO Standards 3.0, we are also somewhat ironically proposing to eliminate subsection 4.1.7 *Sustainability and the Need for Sustainable Development* that was added in the previous revision of the CDIO Syllabus (Crawley et al., 2011). It is no longer relevant to 'hide' sustainable development in a subsection on the X.X.X-level, instead we advocate that different aspects of sustainability and sustainable development should be enhanced and added in several of the sections and subsections as proposed above and in the [Appendix].

Digitalization

Background and motivation

Digital competences were certainly important for graduating engineers in 2001 and 2011 when the previous versions of the CDIO Syllabus were created. Yet, a lot has happened since then. Global connectivity, access to data, and increasing computational capabilities have reshaped the engineering landscape. Digitalization and the emerging technologies have also brought issues in ethics, safety and security to the agenda from new perspectives. Different digital systems have become vital tools in all engineering domains – and they will be important enablers when addressing the Sustainable Development Goals (SDGs) and shaping the future society (UN, 2015; 2020; 2021). One important question is which data literacy skills (Kamp, 2019) shall be taught in the different fields of engineering education for future professionals, and how these skills should be reflected in the CDIO Syllabus.

Method

The theme of digitalization was approached by reflecting the previous versions of the CDIO Syllabus, realizing that the earlier vision of the future of engineering may have put more trust in digital tools than the actual praxis was at the time. Also, the digitalization-driven updates in the CDIO Standards 3.0 (Malmqvist et al., 2020a, b) were revisited, and relevant literature discussing the digitalization-related competences were identified and analyzed. A team of CDIO practitioners reviewed recent publications on impact of digitalization and suggested core digital competences, met on several occasions online to deliberate on the relevance of the findings to CDIO, and where best to locate the skillsets underpinning digital competences.

Results

Digital knowledge and skills are integrated to both discipline-dependent and discipline-independent as well as to professional practice sections of engineering curricula (e.g., Mesároš et al., 2016; Ramadi et al., 2016; Adriole, 2018) which challenges the placement of these competences in the CDIO Syllabus. Accordingly, many articles and reports seem to focus on digitalization-related competences of different fields that made it difficult to identify general guidelines to the work (Gurcan, 2019).

Also, the organization of the cross-cutting themes, and the level of details were discussed (Martín Núñez & Díaz Lantada, 2019; Cruz et al., 2020). That is, some parts (e.g., teamwork) of the CDIO Syllabus might not be deep enough for digitalizations to appear. Should these competences be focused on particular sections, or would it be more appropriate to embed them to the other parts of the Syllabus? We decided to follow the same approach used for the updating of CDIO Standards 3.0 whereby these are infused into various subcategories in the Syllabus instead of having a separate standalone subcategory at X.X level.

The work of van Laar et al. (2017) was found useful, as it identified concepts being used to describe skills needed in a digital environment, that go beyond mere technical use, and focus on 21st century digital skills. The framework these authors offered aligned well with the CDIO Syllabus and the dimensions of digital competences recommended had great overlaps with key categories in CDIO Syllabus. Margarov & Konovalova (2019) on the other hand, proposed four broad categories of digital competences (ICT-skills): general, professional, problem-oriented and complementary. They highlighted three aspects of the digital economy where these skills will be of relevance: cognitive, socio-behavioral, and technological. Oberländer, Beinicke & Bipp (2020) provide a holistic view of the concept of digital competences. They proposed 25 dimensions that constitute digital competences at the workplace. The components underlying these aspects can again be found diffused in the CDIO Syllabus.

Cross-checking was carried out against the current version of the Syllabus and it was found that most had already been covered, albeit in different categories. Hence the work concentrated mostly on updating relevant categories of the existing CDIO Syllabus to reflect application of digital skills and impact of digitalization on education.

Acceleration

Background and motivation

Since 2001, when the CDIO Syllabus 1.0 was published (Crawley, 2001), a number of impactful global events (The Twin Towers, the financial crises of 2008, Space X’s disruption of the space industry, “tipping-point” scenarios driven by global warming, Covid-19 etc.) have highlighted our often very limited pre-understanding of complex, “unknown-unknowns” events, along with the need for urgent, yet appropriate response. Also is society experiencing a moment of great upheaval under the influence of transformative technologies and rapid economic and societal developments. We are living in an age where change in society, technology and science is accelerating at a pace humankind has never seen before. An ever-growing part of the world’s population is becoming digitally connected, has access to a wealth of accumulated knowledge and adds to it in a worldwide collaborative effort. Rapidly evolving markets, changing regulations, breakthroughs in technologies and political instabilities make it hard to look too far into the future. It gives rise to high unpredictability and urgent challenges - environmental, social and economic, and feeds the sense we live in an “accelerating” world where the half-life of expert knowledge and timescales for knowledge acquisition and decision-making are being compressed. Engineering education must prepare students to thrive in this world of flux, to be ready, no matter what comes next. It must empower them to be leaders of innovation, to not only be able to adapt to a changing world, but also to change it.

Method

The identification of acceleration was initiated by a literature search in Scopus and leading engineering education journals and conference proceedings. Few papers were found to focus exclusively on acceleration-related skills, but some informative publications were found, including Passow & Passow (2017), Kamp (2019; 2020), and Margarov & Konovalova (2019).

A team of CDIO practitioners then reviewed the publications on the impact of acceleration, identified acceleration-related themes and topics and proposed some additional categories, topics and aspects as candidates for modification or addition in the CDIO Syllabus 3.0. The group met on several occasions online to discuss the relevance of the findings to CDIO, and where best to locate the acceleration skills.

Results

The acceleration-related themes identified in the literature, included interdisciplinary knowledge and collaborative skills, an extended and more holistic view on "systems", methods for the advanced use and situation analysis, for faster and more exhaustive design space exploration, and for agile and change-driven development processes. Moreover, the important abilities of mental flexibility (like agility and adaptability), self-leadership (like self-confidence and coping with uncertainties), self-directed learning and the development of relationships (like empathy, trust) werere brought forward. As the "acceleration" dimension overlaps with both sustainability (e.g., interdisciplinarity, holistic thinking) and digitalization (e.g., fast access to and reliance on massive datasets, cybersecurity), the text in the paragraphs below aims to minimize repetition of what has already been stated in this paper.

Specifically, in subcategory 2, *Personal and Professional Skills and Attitudes*, the perspective in *2.3 Systems thinking* has expanded from a systems' view focused on deterministic technical systems to one that embraces human-systems interaction, transdisciplinary approaches, uncertainty and complexity. In 2.4 *Attitudes, thought and learning,* a new subcategory 2.4.3 *Adaptability, resourcefulness and flexibility* has been created to collect such competences. The topics are partly redistributed from other categories. In 2.4.7 *Lifelong Learning and Educating*, *Learning agility* has been added to the subcategory heading in order emphasize the need for fast updating of skills and knowledge. Several topics on 2.4.7 are added and/or updated to reflect this expanded scope. In *2.5 Ethics, equity and other responsibilities,* aspects of "acceleration" have been added to the subcategories 2.5.1 *Ethics, Integrity and Social Responsibility*, 2.5.3 *Proactive Vision and Intention in Life*, and 2.5.4 *Equity, Diversity and Inclusiveness* (renamed).

In category 4 *Conceiving, Designing … The Innovation Process*, aspects of "acceleration" that have been added to *4.1 Societal and environmental context,* consider interdisciplinarity (4.1.2 *The Impact of Engineering on Society and the Environment*) and global communities (4.1.7 *Developing a Global and International Perspective)*. The *4.3 Conceiving, Systems engineering and management* has aspect additions to 4.3.2 *Understanding Needs and Setting Goals* – (related to capturing user scenarios and requirements margins) and 4.3.4 *System Engineering, Modeling and Interfaces* – aspects related to "trust" in designed systems and autonomous and self-evolving systems. Several topics have been added to 4.3.5 *Development Project Management* – they reflect a variety of system development and program management processes. *In 4.4 Designing*, an aspect related to very fast design loops have been added to 4.4.1 *The Design Process*. The expanded view of systems is also incorporated in 4.5

Implementing where 4.5.5 *Test, Verification, Validation and Certification* has an added aspect related to validation of systems with evolved, “learned” behaviors.

Finally, an aspect related to developing technology from research observation level to product commercialization has been added to 5.1.8 *Innovation – the Conception, Design and Introduction of New Goods and Services in 5.1 Leading engineering endeavors.*

Experiences from the CDIO community

Background and motivation

While the three first change drivers were related to a major societal trend, the fourth was instead more inward-looking. Here, the impetus to change comes from the practical experiences reported in the CDIO community. In addition to the CDIO conference papers, the survey included the special issue “Scholarly Development of Engineering Education – the CDIO approach” in the European Journal of Engineering Education (Edström, Malmqvist & Roslöf, 2020). Of particular interest is curriculum or course development that addresses learning outcomes that may not yet be fully present in the CDIO Syllabus. Hence, we are searching for work with a scope that goes beyond what was reflected in the CDIO Syllabus 2.0, and that may be taken as arguments for changing or expanding it.

Method

The first stage of the work was to manually go through the proceedings of the International CDIO Conferences 2018-2020, in total 219 papers or 2630 pages, and the special issue mentioned above. The aim was to identify papers addressing aspects of what students should learn, but that were not obviously already covered in the Syllabus. An important criterion was that topics had to be novel and universal, i.e., not subject-dependent. Papers related to sustainability, digitalisation or acceleration were forwarded to the colleagues who were reviewing these themes. For the remaining papers, a closer analysis followed, considering where in the Syllabus the topic could belong and whether it was already present, either in part or under other terms. The analysis was checked by another member of the working group in a round-robin fashion. Finally, the group jointly prioritized the topics, and formulated the proposed changes.

Results

The first result of the investigation of CDIO literature can be seen as a clear validation of the CDIO Syllabus. A very large majority of the work that was reviewed did not warrant changes or additions, mainly because the topics were found to be already sufficiently present in the CDIO Syllabus. This applied to numerous papers addressing topics like life-long learning, self-directed learning, creative thinking and systems thinking, safety, ethics and social responsibility, just to mention a few.

Interdisciplinarity - Several authors note the need to collaborate around solutions for global societal and environmental challenges (Enelund & Henricson Briggs, 2020; Fouw et al., 2020). Besides engineering competences, real-life assignments often demand interdisciplinary and transdisciplinary systems thinking, and an open entrepreneurial mindset (Klaassen et al., 2020; Boon, 2018; MacLeod, 2018; Spelt, 2017). Engineering students need to discover that it is impossible to know enough to fully understand wicked problems (Kamp, 2019). Such problems may require an interdisciplinary approach, with multiple disciplines involved, or even transdisciplinary - beyond the current disciplinary map. While already present in the Syllabus, it was proposed to strengthen holistic thinking and transdisciplinary approaches in sections 2.4.3, 2.4.4, 2.5.5. and 4.1.2.

Internationalization - As noted by Salti et al. (2019), "*Embedding the internationalization process within the CDIO context would certainly benefit the higher education institutions and the attributes of their graduates*" (p.20). It is increasingly important to see cultural differences and opportunities in a more globalized world where products, systems and services are delivered not just locally but globally (Van Puffelen & van Oppen, 2020; Mejtoft et al., 2020; Kjellgren, et al., 2018). According to Säisä et al. (2020), international connections and activities are typical in project-oriented organizations in many engineering domains. Similar considerations are also coming from the sustainability and acceleration perspectives. The need is also indicated by the optional CDIO standard for Internationalization and Mobility (Malmqvist et al., 2020). Internationalization is present in the Syllabus, but the competences need to be made more explicit or precisely described. As a result, modifications are proposed in 2.3.1, 2.4.4, 2.4.5, 3.1, 3.2.2, 4.1.2, and 4.1.7.

Development methodology - Over the years, methods and tools for developing engineering products, systems and services have developed, increasingly based on incremental development to ensure quicker time-to-market and a focus on families of products, systems and services (Säisä et al., 2018, D Ha et al., 2019). We also note that the expression "conceive - design - implement - operate" is sometimes misconceived as implying a linear or waterfall development process. We propose modifying 4.4.2 and 4.6.3 to cover a diversity of methods.

History of Technology - Smulders et al. (2018) propose that students should learn about the process of technological innovation in the history of technology, combining an innovation theoretical lens with a socio-interactive lens to bring the stories to life: "*What troubles did they encounter? What assumptions were needed to go and how was it accepted? How did they conquer resistance to change?*" When the historical context is brought up in section 4.1.4, this perspective has indeed been lacking and we propose to add: "The history of technological innovation and how society and technology have co-evolved".

Research - The work by Gunnarsson et al. (2019) mentions the LiTH Syllabus, a modified version of the CDIO Syllabus developed and used at Linköping University (2019). The major adaptation there is to add a new section that enables the use of the CDIO framework by also non-engineering programs.. The section covers various aspects of defining, executing and reporting research and development projects. Also Chuchalin (2020) addresses research skills. Many engineering programs contain a research project, most often in the form of thesis work but also other types of undergraduate research projects are increasingly implemented as learning activities. We find the research competence a welcome addition. While some aspects are already present in 2.2 *Experimentation, investigation and knowledge discovery*, these can be extended to embrace a more general view on research approaches and methodologies. We propose to add a section 5.3 *Research*, with four subtopics: 5.3.1 *Identification of needs, structuring and planning of research projects*; 5.3.2 *Execution of research*; 5.3.3 *Presentation and evaluation of research*; 5.3.4 *Research ethics*.

Learning through reflective practice - Junaid et al. (2018) bring up the skills and habits associated with keeping professional logbooks. Among various functions this can generate reflection that supports the engineer to develop professionally through their own work. Junaid et al. refer to Ericssen's concept of deliberate practice, i.e., practice with the aim of improving expertise and performance. We see no reason to specify a particular genre of writing in 3.2 Communication skills. However, in that section, writing was never seen as a tool for reflection or self-development, and we propose adding “Reflective writing (writing to learn)”. Likewise, in 2.4.6 Lifelong Learning and Educating we propose to add “Learning from experience through reflective practice”. While reviewing 2.4.6 we also note the mention of learning styles. These are contested and seen by many researchers as urban myths (see for instance Coffield, 2012). We therefore propose to remove “One’s own learning styles”.

DISCUSSION

Evolution vs. revolution

It has been ten years since the CDIO Syllabus was last revised (in 2011), and within the CDIO community there is a widespread understanding and consensus that it is now timely and necessary to update the Syllabus. Engineering education development needs to take into account the development of society and technology, and keeping the CDIO Syllabus current is a way to support this.

The discussion is however to what degree the work should be incremental or radical. There is at the moment an unresolved tension between being compatible with current educational practices and positioning CDIO as far more future-oriented. For example, some call for higher education to move beyond the idea of detailed pre-conceived curricula, toward models where students have more agency of the directions of their studies (see e.g. Osberg & Biesta, 2020). Others have identified a need for changes in adult learning where people move into and out of higher education throughout their professional careers, taking only shorter and more focused courses (Mense et al., 2018). Such changes could have profound implications for the CDIO approach. However, the exploration of such implications is beyond the scope of the current set of revisions.

The Syllabus has been updated to be backwards compatible in numbering and general structure even as the contents have been extensively expanded and modified. The Syllabus is an important instrument that this group has wished to keep intact for the purpose of helping practitioners who have already invested in its use. There is for instance among current users of the Syllabus an interest in preserving continuity in their local curriculum documentation, for instance regarding the numbering of topics. While retaining the structure was not always compatible with the wish for a simple and logical document, it has here been accommodated to the extent possible. Changes on the higher levels are proposed only after much consideration. It has been far easier to propose updates to the lower-level descriptions of the topics. The update contains a very large number of such edits, in particular in the lists below the X.X.X level.

Furthermore, the changes proposed here are less often about removing topics, since there could be stakeholders for whom an item is (still) important. The Syllabus aims to be comprehensive, and contain a wide range of topics that *could* be addressed in an education, and a topic is thus never prescriptive. Therefore, it generally makes more sense to add or elaborate on topics, or choose broader terms that cover more ground.

On the other hand, allowing the document to sprawl creates challenges of its own, perhaps particularly to new collaborators. The alternative would be to start from a blank slate and make the resulting document as “clean” and accessible as possible. While this “revolutionary” approach would require an even larger effort of the community than was made here, it could certainly be in the interest of many collaborators, not least because there are benefits in participating in such a full process. This option could therefore be considered in future revisions.

Inherent tensions

The process of revising the Syllabus was conducted in subgroups along the different change drivers. They used different sets of sources and stimulus for revisions. The sustainability group used research and reports on changes to education that seek to enable a new, sustainable direction of societal development. As a basis for promoting changes to education in general and engineering education in particular, such literature argues that the acceleration of human economic activity is a root cause for our current predicament and requires radical departures from current societal and educational practices. In contrast, the acceleration subgroup identified trends of increased acceleration as a call to support students in a work environment likely to change at an ever-faster rate. In our work, we did not necessarily take into account that the different values at work here could be contradictory, nor how CDIO students should position themselves with respect to such accelerating increase in economic activities: to embrace them, to understand them or even challenge or reject them.

Global representation and relevance

The number of people who have been mainly involved in this work is limited, and many of them come from just some parts of the world. This implies a risk that the review is made with limited perspectives. It has been mitigated by inviting the whole CDIO community in an open review process with opportunity to give feedback. Enhanced perspectives are also included through the literature that is underlying the Syllabus revision, with papers by authors from and other parts of Africa, Asia, Europe, North and South America, and reports from international bodies such as IPCC, UNESCO, and WWF. However, it can always be discussed or questioned if this has been enough to accomplish an update of the Syllabus that does not miss certain perspectives or is biased towards a certain direction. A conclusion from these experiences for future reviews, is to ensure that global representation and participation are taken into account.

The Syllabus is not an objective, value-free document. It must be noted that some of the inherent values might be more representative for democratic societies. This can be challenging in contexts where the overall societal and political climate is more restrictive. Engineering educators in authoritarian regimes could find great difficulties in addressing some of the new topics in the Syllabus, such as inclusiveness and collaborations. There may for instance be contexts where the inclusion of *Diverse, Underrepresented, and Conflicting Stakeholders input* (3.1.3) could put engineers at serious professional or even personal risk.

Recommendations for future work

Updating the CDIO Syllabus to version 3.0 offers an opportunity to renew the validation with current professional practice. Another avenue is to investigate how the Syllabus is used among CDIO implementers, and create support for the users. For instance, the Syllabus is intended to aid the formulation of learning outcomes for engineering degree programs. However, as noted earlier by Crawley (2001), it is not an instrument that is sufficient for directly formulating learning outcomes. With the current revision adding many new topics to the overall Syllabus, the task of finding meaningful, cohesive subsets of topics of relevance for degree programs may become even more challenging. Future work that supports new adopters in using the Syllabus to formulate learning outcomes would be welcome.

As always, the CDIO community is encouraged to use the new version and report experiences, and to formulate lessons learned and critique that can inform future updates. One practical way to enable monitoring of such work is to add keywords to conference papers in which the Syllabus or particular Syllabus topics are addressed. While the Syllabus aims to be comprehensive, it should never be seen as complete and final. In addition to the updates presented and discussed in this paper, we fully expect further additions and changes that may become necessary by specific local needs, evolved understandings and knowledge, and changes in future circumstances.

In 2011, the CDIO Syllabus 2.0 (Crawley et al., 2011) was compared with a number if international and national standards for engineering education accreditation, including ABET, EUR-ACE, the British UK-SPEC, the Swedish degree ordinance and the Canadian CEAB, and it was concluded that "*The CDIO Syllabus states outcomes for engineering education that reflect a broader view of the engineering profession, and its greater levels of detail facilitate program and course development. A program whose design is based on the CDIO Syllabus will also satisfy its national requirements for specified program outcomes*". Of course also these other standards have been updated. For example, ABET has made amendments to its student outcomes accreditation criteria, which will be effective for the 2019-20 academic year. (ABET, n.a.). The EUR-ACE standards (ENAEE, 2011) have also been updated, as recently as 2021. Taking into consideration the changes in ABET, EUR-ACE, and other accreditation standards will be worthwhile for CDIO to review its mapping to these standards in terms of the new Syllabus version 3.0.

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CDIO SYLLABUS 3.0 - PROPOSAL APRIL 15 2022

This document is the current working version of the proposal for the CDIO Syllabus 3.0.

The working group was organized in four sub-groups, each focusing on a certain change driver:

Group 1 - Sustainable development
Group 2 - Digitalization
Group 3 - Acceleration
Group 4 - Experiences from the CDIO community

To keep track of the modifications, please mark suggested syllabus modifications as follows:

- changes and additions related to Sustainability
- changes and additions related to Digitalization
- changes and additions related to Acceleration
- changes and additions related to Experiences from the CDIO community

Note: since the whole Syllabus reflects previous work it is not feasible highlight titles/text that is already in place related to Experiences from the CDIO community

CDIO Syllabus to be updated from 2.0 to 3.0:

1 FUNDAMENTAL KNOWLEDGE AND REASONING

1.1 KNOWLEDGE OF UNDERLYING MATHEMATICS AND SCIENCES

1.1.1 Mathematics (including statistics)
1.1.2 Physics
1.1.3 Chemistry
1.1.4 Biology

1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE

1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, METHODS AND TOOLS

1.4 KNOWLEDGE OF SOCIAL SCIENCES AND HUMANITIES

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES

2.1 ANALYTIC REASONING AND PROBLEM SOLVING

2.1.1 Problem Identification and Formulation

- Data (including big data) and symptoms
- Assumptions and sources of bias
- Issue prioritization in context of overall goals
- A plan of attack (incorporating model, analytical and numerical solutions, qualitative analysis, experimentation and consideration of uncertainty)

2.1.2 Modeling

- Assumptions to simplify complex systems and environment
- Conceptual and qualitative models
- Quantitative models and simulations
  - Re-usable simulation models using reference architectures
  - Data mining and analytics
  - Limitation of models used in digital tools
- Diagnostic, descriptive, predictive and prescriptive models

2.1.3 Estimation and Qualitative Analysis

- Orders of magnitude, bounds and trends
- Tests for consistency and errors (limits, units, etc.)
- The generalization of analytical solutions

2.1.4 Analysis with Uncertainty

- Incomplete and ambiguous information
- Probabilistic and statistical models of events and sequences
- Engineering cost-benefit and risk analysis
- Decision analysis
- Margins and reserves

2.1.5 Solution and Recommendation

- Problem solutions
- Essential results of solutions and test data
- Discrepancies in results
- Summary recommendations
- Possible improvements in the problem-solving process

2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY

2.2.1 Hypothesis Formulation

- Critical questions to be examined
- Hypotheses to be tested
- Controls and control groups

2.2.2 *Survey of Literature*

The literature and media research strategy
Information search and identification using library, on-line and database tools
Sorting and classifying the primary information
The quality and reliability of information
The essentials and innovations contained in the information Research questions that are unanswered
Citations to references

2.2.3 *Experimental Inquiry*

The experimental concept and strategy
The ethical considerations when humans and animals are used in experiments
Investigations based on social science methods
Experiment construction
Experiment planning including design of experiments
Test protocols and experimental procedures Experimental measurements
Experimental data mining and analysis (classification, regression, correlation etc)
Experimental data
- Quantity, relevance and reliability of big data information
- Data management
  - Building data sets required to train algorithms
  - Storage, management and re-use of research and project data.

Experimental data vs. available models

2.2.4 *Hypothesis Test and Defense*

The statistical validity of data
The limitations of data employed
Analysis and conclusions, supported by data
Possible improvements in knowledge discovery process

2.3 SYSTEM THINKING

2.3.1 *Thinking Holistically*

Ecological and planetary systems, and how humans, societies, and artefacts (e.g. technology), are embedded in and rely on these systems
A technical (including cyberphysical) system, its function and behavior, and its elements
The social, environmental, economic, and technical context of technical systems
Human-system integration and interaction
The interactions external to the system, and the behavioral impact of the system
How systems are embedded within different domains and different scales
The system life-cycle from cradle to cradle
Transdisciplinary approaches that ensure the technical system and its social, environmental, and economic context is understood from all relevant perspectives
- Acceptance of the unknown, the unexpected, the unforeseeable
- Openness, tolerance of ideas and truths different from our own
- Metaphors as ways to illustrate the complexity of social problems

2.3.2 *Emergence and Interactions in Systems*

The abstractions necessary to define and model the entities or elements of the system
The important relationships, interactions and interfaces among elements
The functional and behavioral properties (intended and unintended) that emerge from the system, during design and operation
Evolutionary adaptation over time
Cause-effect chains, cascading effects, feedback loops, delays
Tipping points, resilience, adaptation

2.3.3 *Prioritization and Focus*

All factors relevant to the system in the whole
The driving factors from among the whole
Energy and allocations to resolve the driving issues

2.3.4 *Trade-offs, Synergies, Judgment and Balance in Resolution*

Tensions and factors to resolve through trade-offs

Solutions that balance various factors, resolve tensions and optimize the system as a whole

Flexible vs. optimal solutions over the system lifetime

Possible improvements in the system thinking used

2.4 ATTITUDES, THOUGHT AND LEARNING

2.4.1 *Initiative and Willingness to Make Decisions in the Face of Uncertainty*

Initiative taking

Leadership in new endeavors, with a bias for appropriate action

Decisions, based on the information at hand

Development of a course of action

The potential benefits and risks of an action or decision

The recognition of one's feelings and desires related to decisions

2.4.2 *Perseverance, Urgency and Will to Deliver*

Sense of responsibility for outcomes

Self-confidence, courage and enthusiasm Determination to accomplish objectives

The importance of hard work, intensity and attention to detail

Definitive action, delivery of results and reporting on actions

2.4.3 *Adaptability, resourcefulness and flexibility*

Adaptation to change

Leverage opportunities arising from the resources of the situation, group or evolving contexts

A readiness, willingness and ability to work independently

A willingness to work with others, and to consider and embrace various viewpoints

An acceptance of feedback, criticism and willingness to reflect and respond and deal with associated emotions and feelings

The balance between personal and professional life

2.4.4 *Creative Thinking*

Conceptualization and abstraction Synthesis and generalization

The process of invention

Collaborative, multidisciplinary creative thinking

Computational tools for creative thinking

The role of creativity in art, science, the humanities and engineering

2.4.5 *Critical Thinking*

Purpose and statement of the problem or issue Assumptions

Logical arguments (and fallacies) and solutions

Reviewing and supporting evidence, facts and information

Points of view and theories

Conclusions and implications - including societal and multidisciplinary aspects

Reflection on the quality of the thinking

Question norms, practices and opinions

Reflect on one's own values, perceptions and actions

2.4.6 *Self-Awareness, Self-Reflection, Metacognition and Knowledge Integration*

Self-reflection - One's skills, interests, strengths and weaknesses

Reflect on willingness, effectiveness, flexibility and motivation

Recognize one's feelings and desires and ability to deal with them

The extent of one's abilities, and one's responsibility for self-improvement to overcome important weaknesses

The importance of both depth and breadth of knowledge

Identification of how effectively and in what way one is thinking

Linking knowledge together and identifying the structure of knowledge

One's own role in the local community and (global) society

Wellbeing in a complex and changing world

2.4.7 Learning agility, Lifelong Learning and Educating

The motivation for continued self-education

The skills of self-directed learning

Learning from experience through reflective practice

Flexibility in one's learning approaches

Enabling learning in and from others

Sharing best practices and lessons learned

Relationships with mentors and mentees

Proactively advocating and infusing technology advances

2.4.8 Time and Resource Management

Task prioritization

The importance and/or urgency of tasks

Interdependency of tasks

Efficient execution of tasks

2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES

2.5.1 Ethics, Integrity and Social Responsibility

One's ethical standards, principles, values, and preferences

The moral courage to act on principle despite adversity

The possibility of conflict between professionally ethical imperatives

Artificial Intelligence and Ethics

Discern validity, applicability and implications of recommendations from AI

Prepared for debates about values, ethics, morality

A commitment to service

Truthfulness, bias, data manipulation

A commitment to help others and society more broadly and to contribute to transformations for sustainability

Concepts of justice, fairness, and responsibility

Analysis, judgement, and argumentation in ethical issues

The precautionary principle

2.5.2 Professional Behavior

A professional bearing Professional courtesy

International customs and norms of interpersonal contact

Professional conduct in social media

2.5.3 Proactive Vision and Intention in Life

A personal vision for one's future

Job crafting

Aspiration to exercise his/her potentials as a leader

One's portfolio of professional skills

Considering one's contributions to the local community and (global) society

Inspiring others

Continually evaluate and further motivate one's actions

2.5.4 Staying Current on the World of Engineering

The potential impact of new scientific discoveries on engineering

The social, environmental, economic, and technical impact of new technologies and innovations, positive as well as negative

A familiarity with current practices/technology in engineering

The links between engineering theory and practice

The links between engineering and other disciplines, including social sciences and humanities

2.5.5 Equity, Diversity and Inclusiveness

A commitment to treat others with equity and justice, including gender, race, ethnicity, religion, etc.

Global and intergenerational equity and justice

Embracing diversity and inclusiveness in groups and workforce

Empathize with others

Cultural differences in concepts of time, future, development, and progress

2.5.6 *Trust and Loyalty*
Loyalty to one's colleagues and team
Recognizing and emphasizing the contributions of others
Working to make others successful

3 INTERPERSONAL SKILLS: COLLABORATION, TEAMWORK, AND COMMUNICATION

3.1 TEAMWORK AND COLLABORATION

3.1.1 *Working in teams*
Forming teams, assigning roles and responsibilities
Setting goals and objectives, planning, scheduling the work
Setting norms (ground rules, respect and diversity, confidentiality, accountability)
Coordination and management of team process: meetings - physical and distance; communication - information, listening, feedback; decision-making; documentation and reporting; representing the team
Team membership and leadership (delegating, facilitating, directing, supporting, coaching)
Handling diverse perspectives and conflicts
Creativity, empowerment and motivation (incentives, recognition)
Strategies for assessment and reflection to develop processes, team and members

3.1.2 *Multi-perspective Collaboration*
Facilitation of diversity and inclusiveness in group processes across cultures, social groups and communities
Using knowledge and methods from other disciplines outside engineering in addressing problems
Multidisciplinary vs. cross-disciplinarity vs. interdisciplinary vs. transdisciplinary

3.1.3 *Stakeholder Engagement*
Co-creation and stakeholder engagement techniques
Incorporation of diverse, underrepresented, and conflicting stakeholders' input
Understand the influence of values on stakeholder actions and activities

3.1.4 *Establishing Diverse Connections and Networking*
Appreciating those with different skills, cultures or experiences
Engaging and connecting with diverse individuals
Building extended social networks, in person and digital
Activating and using networks to achieve goals

3.2 COMMUNICATIONS

3.2.1 *Communications Strategy*
The communication situation
Communications objectives
The needs and character of the audience
The communication context
The appropriate combination of media
A communication style (proposing, reviewing, collaborating, documenting, teaching)
The content and organization

3.2.2 *Communications Structure*
Logical, persuasive arguments
The appropriate structure and relationship amongst ideas
Relevant, credible, accurate supporting evidence
Conciseness, crispness, precision and clarity of language
Rhetorical factors (e.g., audience bias)
Cross-disciplinary cross-cultural and international communications

3.2.3 Written Communication

Writing with coherence and flow

Writing with correct spelling, punctuation and grammar Formatting the document

Technical writing

Various written styles (informal, formal memos, reports, resume, etc.)

Reflective writing (writing to learn)

3.2.4 Digital Communication

Preparing multimedia presentations (video, immersive technologies)

The norms associated with the use of social media, e-mail, and online meetings

3.2.5 Graphical Communications

Sketching and drawing

Construction of tables, graphs, charts, data visualization

Formal technical drawings and renderings

Use of digital tools for graphical communication

3.2.6 Oral Presentation

Preparing presentations and supporting media with appropriate language, style, timing and flow

Appropriate nonverbal communications (gestures, eye contact, poise) Answering questions effectively

Pitching

3.2.7 Inquiry, Listening and Dialog

Listening carefully to others, with the intention to understand

Asking thoughtful questions of others

Processing diverse points of view Constructive dialog

Recognizing ideas that may be better than your own

Body language and the silent voice.

3.2.8 Negotiation, Compromise and Conflict Resolution

Identifying potential disagreements, tensions or conflicts

Negotiation to find acceptable solutions

Reaching agreement without compromising fundamental principles

Diffusing conflicts

Identify value differences and trade-offs, e.g., among different courses of actions

3.2.9 Advocacy

Clearly explaining one's point of view

Explaining how one reached an interpretation or conclusion

Assessing how well you are understood

Adjusting approach to advocacy on audience characteristics

3.3 COMMUNICATIONS IN FOREIGN LANGUAGES

3.3.1 Communications in English

3.3.2 Communications in Languages of Regional Commerce and Industry

3.3.3 Communications in Other Languages

4 CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS

4.1 SOCIETAL AND ENVIRONMENTAL CONTEXT

4.1.1 Roles and Responsibility of Engineers

The goals and roles of the engineering profession

The responsibilities of engineers to society and a sustainable future

One's own role and impact as a responsible engineer in promoting a sustainable society

4.1.2 The Impact of Engineering on Society and the Environment

The impact of engineering on the environmental, social, knowledge and economic systems

Using interdisciplinary knowledge and skills to understand and address complex problems

Assessment of sustainability effects/impacts

Measures and strategies for mitigating/eliminating negative impacts and promoting/enhancing positive impacts

4.1.3 Society's Regulation of Engineering

The role of society and its agents to regulate engineering

The way in which legal and political systems regulate and influence engineering

How professional societies license and set standards

How intellectual property is created, utilized and defended

Protection of personal data and information (GDPR etc)

4.1.4 The Historical and Cultural Context

The diverse nature and history of human societies as well as their literary, philosophical and artistic traditions

The history of technological innovation and how society and technology have co-evolved

Learning from historical and cultural contexts about sustainability issues and potential solutions

4.1.5 Contemporary Issues and Values

The important contemporary political, social, legal and environmental issues and values

The processes by which contemporary values are set, and one's role in these processes

The mechanisms for expansion and diffusion of knowledge

Definitions and principles of sustainability and sustainable development

4.1.6 Visions of the Future

Concepts about the future, including long-term, short-term; possible, probable, plausible and desirable

Scenario construction, forecasting, backcasting and visioning

Visions for a sustainable future for the society and for one's profession

4.1.7 Developing a Global and International Perspective

The internationalization of human activity

The similarities and differences in the political, social, economic, business and technical norms of various cultures

International and intergovernmental agreements and alliances

Unofficial global communities and network

Postcolonialism

Consequences of technical systems in a global perspective

One's own role and possibilities to have a global impact

4.2 ENTERPRISE AND BUSINESS CONTEXT

4.2.1 Appreciating Different Enterprise Cultures

The differences in process, culture, and metrics of success in various enterprise cultures:

- Corporate vs. academic vs. governmental vs. non-profit/NGO
- Market vs. policy vs. value driven
- Large vs. small
- Centralized vs. distributed
- Research and development vs. operations
- Mature vs. growth phase vs. entrepreneurial
- Longer vs. -shorter development cycles
- With vs. without the participation of organized labor

Proactive vs. reactive in a transformation towards a sustainable future

4.2.2 Enterprise Stakeholders, Strategy and Goals

The stakeholders and beneficiaries of an enterprise (owners, employees, customers, etc.)
People in other contexts, future generations, and other species, as stakeholders
Obligations to stakeholders
The mission, scope and goals of the enterprise
Enterprise strategy and resource allocation
An enterprise's core competence and markets
Key alliances and supplier relations

4.2.3 Technical Entrepreneurship

Entrepreneurial opportunities that can be addressed by technology
Technologies that can create new products, systems, and services that contribute to sustainable development
Commercial value of data and information
Entrepreneurial finance and organization

4.2.4 Working in Organizations

The function of management
Various roles and responsibilities in an organization
The roles of functional and program organizations
Working effectively within hierarchy and organizations Change, dynamics and evolution in organizations

4.2.5 Working in International Organizations

Culture and tradition of enterprise as a reflection of national culture
Equivalence of qualifications and degrees
Governmental regulation of international work

4.2.6 New Technology Development and Assessment

The research and technology development process
Identifying and assessing emerging technologies that
- might disrupt the business rules, processes, and models,
- can contribute to sustainable development
- can give rise to unintended and unwanted consequences

Technology development roadmaps
Intellectual property regimes and patents
Open innovation

4.2.7 Engineering Project Finance and Economics

Financial and managerial goals and metrics
Project finance – investments, return, timing
Financial planning and control
Impact of projects on enterprise finance, income and cash

4.3 CONCEIVING, SYSTEM ENGINEERING AND MANAGEMENT

4.3.1 Understanding Societal and Planetary Goals and Constraints

Needs vs. wants with respect to justice and sufficiency
Conditions for operating within planetary boundaries and social foundations for human societies
Power, politics, authority in strategy building and change
Theories and dynamics of change (e.g., behaviour change, societal transitions)
Barriers including obstacles, inertia, path dependencies

4.3.2 Understanding Needs and Setting Goals

Needs and opportunities
Customer, user and stakeholder needs
- Capture user experiences and use case scenarios

Opportunities that derive from new technology or latent needs
Factors that set the context of the system goals
- Enterprise goals, strategies, capabilities and alliances
- Competitors and benchmarking information
- Ethical, social, environmental, legal and regulatory influences and constraints
- The probability of change in the factors that influence the system, its goals and resources available

System goals and requirements
- The language/format of goals and requirements
- Initial target goals (based on needs, opportunities and other influences)
- System performance metrics
- Requirement completeness and consistency
- Allocation of margins, responding to change and handling unknown or unanticipated requirements during the lifecycle of a design

4.3.3 Defining Function, Concept and Architecture

Necessary system functions (and behavioral specifications) System concepts
Incorporation of the appropriate level of technology
Trade-offs among and recombination of concepts
High-level architectural form and structure
The decomposition of form into elements, assignment of function to elements, and definition of interfaces

4.3.4 System Engineering, Modeling and Interfaces

Appropriate models of technical performance and other attributes Consideration of implementation and operations
Life cycle value and costs (economic, social, environmental, design, implementation, operations, opportunity, etc.)
Trade-offs among various goals, function, concept and structure and iteration until convergence
'Trusted' system design (addressing aspects of cyber security, data privacy, consumer understanding, transparency)
System designs that are non-deterministic, that continue to learn and modify themselves during operation (e.g., critical decisions that are allocated to autonomous vehicles).
Plans for interface management

4.3.5 Development Project Management

Waterfall, agile and scrum project management models
Project control for cost, performance and schedule
Short-term and long-term impact assessment
Appropriate transition points and reviews
Configuration management and documentation
Performance compared to baseline
Earned value recognition
The estimation and allocation of resources Risks and alternatives
Possible development process improvements
Multi-project and program management
Continuous deployment and DevOps

4.3.6 Product information and knowledge management

Capturing data and crafting a design in a digital environment.
Model-based systems engineering, using digital representations of the system, simulations, and immersive technologies
Digital SE as part of digital end-to-end business
Modeling, visualization and digital representation of system designs and end-to-end solutions
Digital twins
Knowledge sharing; data stewardship, open data sets

4.4 DESIGNING

4.4.1 The Design Process

Requirements for each element or component derived from system level goals and requirements
Alternatives in design
The initial design
Life cycle consideration and responsibility in design (economic, social, environmental)
Experimental prototypes and test articles in design development
Appropriate optimization in the presence of constraints
Iteration until convergence
The final design
Accommodation of changing requirements
Fast generation of multiple design options and evaluating them instantly in a virtual environment ('Optioneering')
What-if scenario analysis

4.4.2 The Design Process Phasing and Approaches

The activities in the phases of system design (e.g. conceptual, preliminary and detailed design)
Process models appropriate for particular development projects (agile, waterfall, spiral, concurrent, set-based design, etc.)
The process for single, platform and derivative products

4.4.3 Utilization of Knowledge in Design

Technical and scientific knowledge
Modes of thought (problem solving, inquiry, system thinking, creative and critical thinking)
Prior work in the field, standardization and reuse of designs (including reverse engineering and refactoring, redesign)
Design knowledge capture

4.4.4 Disciplinary Design

Appropriate techniques, digital tools and processes
Design tool calibration and validation Quantitative analysis of alternatives
Modeling, simulation, visualization and test
Analytical refinement of the design

4.4.5 Multidisciplinary Design

Interactions between disciplines
Dissimilar conventions and assumptions
Differences in the maturity of disciplinary models
Multidisciplinary design environments (physical and digital)

4.4.6 Design for Performance, Sustainability, Safety, Aesthetics, Operability and Other Objectives

Design for:
Performance, quality, robustness, life cycle cost and value
Sustainability:
Life cycle perspective for a product or service
Circular economy
Systems perspective including environmental, social and economic aspects
Efficient and reduced use of energy, materials and land
Reduce/eliminate environmental impact
Reusability, remanufacturing, recycling, retirement
Safety and security
Aesthetics
Implementation, verification, test
Operations
Human factors, interaction and supervision
Delivery channels and service models (e.g. cloud, software-as-a-service, product-service system …)

Reliability, availability, maintainability, dependability, failure mode and effects analysis
Evolution, product improvement

4.5 IMPLEMENTING

4.5.1 Designing a Sustainable Implementation Process

The goals and metrics for implementation performance, cost and quality
The implementation system design:
Task allocation and cell/unit layout
Work flow
Considerations for human
user / operator
Cyberphysical factory design
Consideration of sustainability

4.5.2 Hardware Manufacturing Process

The manufacturing of parts
The assembly of parts into larger constructs
Tolerances, variability, key characteristics and statistical process control

4.5.3 Software Implementing Process

The breakdown of high-level components into module designs (including algorithms and data structures)
Algorithms (data structures, control flow, data flow)
The programming language and paradigms
The low-level design (coding)
The system build

4.5.4 Hardware Software Integration

The integration of software in electronic hardware (size of processor, communications, etc.)
The integration of software with sensor, actuators and mechanical hardware
Hardware/software function and safety
Cyber-Physical systems

4.5.5 Test, Verification, Validation and Certification

Test and analysis procedures (hardware vs. software, acceptance vs. qualification)
The verification of performance to system requirements
The validation of performance to customer needs
The validation of system design behavior, performance and safety of system designs with "learned" behaviors.
The certification to standards

4.5.6 Implementation Management

The organization and structure for implementation Sourcing and partnering
Supply chains and logistics
Control of implementation cost, performance and schedule
Quality assurance
Human health and safety
Environmental security
Possible implementation process improvements

4.6 OPERATING

4.6.1 Designing and Optimizing Sustainable and Safe Operations

The goals and metrics for operational performance, cost and value
Sustainable operations
Safe and secure operations
Operations process architecture and development
Operations (and mission) analysis and modeling

4.6.2 Training and Operations

Training for professional operations: Simulation

Instruction and programs

Procedures

Education for consumer operation

Operations processes

Operations process interactions

4.6.3 Supporting the System Life Cycle

Maintenance and logistics

Life cycle performance and reliability

Life cycle value and costs (economic, social, environmental)

Feedback to facilitate system improvement

Continuous development

4.6.4 System Improvement and Evolution

Pre-planned product improvement

Improvements based on needs observed in operation

Evolutionary system upgrades

Contingency improvements/solutions resulting from operational necessity

4.6.5 Disposal, End-of-Life, and Circularity

The end of useful life Disposal options

Residual value at life-end

Waste hierarchy (reduce, reuse, repair, recycle, recover, disposal)

Environmental and social considerations and constraints for disposal

Circularity

4.6.6 Operations Management

The organization and structure for operations

Partnerships and alliances

Control of operations cost, performance and scheduling

Quality and safety assurance

Possible operations process improvements

Life cycle management

Human health and safety

Environmental security

5 THE EXPANDED CDIO SYLLABUS: LEADERSHIP, ENTREPRENEURSHIP AND RESEARCH

These expansions of the core CDIO Syllabus are provided as a resource for programs that seek to respond to stakeholder expressed needs in the areas of Engineering Leadership and Entrepreneurship. Some topics, such as Engineering Research may also be expected in master's degree CDIO programs.

5.1 LEADING ENGINEERING ENDEAVORS

Engineering Leadership builds on factors already included above, including:

- **Attitudes of Leadership – Core Personal Values and Character,** including topics in Attitudes, Thought and Learning (2.4), and in Ethics, Equity and Other Responsibilities (2.5)
  Relating to Others, including topics in Teamwork and Collaboration (3.1) and Communication (3.2) and potentially Communications in Foreign Languages (3.3)
- **Making Sense of Context**, including topics in Societal and Environmental Context (4.1), Enterprise and Business Context (4.2) Conceiving, Systems Engineering and Management (4.3) and System Thinking (2.3)

In addition, there are several topics that constitute creating a **Purposeful Vision**:

5.1.1 Identifying the Issue, Problem or Paradox (which builds on Understanding Needs and Setting Goals 4.3.2)

Synthesizing the understanding of needs or opportunities (that relate to technical systems)
Clarifying the central issues
Framing the problem to be solved
Identifying the underlying paradox to be examined

5.1.2 Thinking Creatively and Communicating Possibilities (which builds on and expands Creative Thinking 2.4.3)

How to create new ideas and approaches
New visions of technical systems that meet the needs of customers and society
Communicating visions for products and enterprises
Compelling and holistic visions for the future

5.1.3 Defining the Solution (which builds on and expands Understanding Needs and Setting Goals 4.3.2)

The vision for the engineering solution
Achievable goals for quality performance, budget and schedule
Consideration of direct and indirect stakeholders
Consideration of technology options
Consideration of regulatory, political and competitive forces
Collaboration with direct and indirect stakeholders in outlining interventions

5.1.4 Creating New Solution Concepts (which builds on and expands 4.3.2 and 4.3.3)

Setting requirements and specifications
The high-level concept for the solution
Architecture and interfaces
Alignment with other projects of the enterprise
Alignment with enterprise strategy, resources and infrastructure

And several topics that lead to **Delivering on the Vision:**

5.1.5 Building and Leading an Organization and Extended Organization (which builds on 4.2.4 and 4.2.5)

Recruiting key team members with complementary skills
Start-up of team processes, and technical interchange
Defining roles, responsibilities and incentives
Leading group decision-making
Assessing group progress and performance
Building the competence of others and succession Partnering with external competence
Continuous self-evaluation in relation to collaboration, teamwork and leadership
Ability to show leadership that recognizes feelings and varying desires

5.1.6 Planning and Managing a Project to Completion (which builds on 4.3.4)

Plans of action and alternatives to deliver completed projects on time
Deviation from plan, and re-planning
Managing human, time, financial and technical resources to meet plan
Program risk, configuration and documentation
Program economics and the impact of decisions on them
Interfaces to program and project portfolio management in large-scale environments
Continually evaluate and further motivate one's actions in managing a project and its members and stakeholders

5.1.7 *Exercising Project/Solution Judgment and Critical Reasoning (which builds on 2.3.4, 2.4.4, 2.4.5, 2.5.3)*

Making complex technical decisions with uncertain and incomplete information
Questioning and critically evaluating the decisions of others
Corroborating inputs from several sources
Evaluating evidence and identifying the validity of key assumptions
Understanding alternatives that are proposed by others
Judging the expected evolution of all solutions in the future

5.1.8 *Innovation – the Conception, Design and Introduction of New Goods and Services (which is the leadership of 4.3 and 4.4)*

From research to readiness for industrial application and commercialization
Designing and introducing new goods and services to the marketplace
Designing solutions to meet customer and societal needs
Designing solutions with the appropriate balance of new and existing technology
Robust, flexible and adaptable products
Consideration of current and future competition
Validating the effectiveness of the solution

5.1.9 *Invention – the Development of New Devices, Materials or Processes that Enable New Goods and Services (which builds on 4.2.6)*

Science and technology basis and options Imagining possibilities
Inventing a practical device or process that enables a new product or solution
Adherence to intellectual property regimes

5.1.10 *Implementation and Operation – the Creation and Operation of the Goods and Services that will Deliver Value (which are the leadership of 4.5 and 4.6)*

Leading implementing and operating Importance of quality
Safe operations
Operations to deliver value to the customer and society

These last three items are in fact the leadership of the core processes of engineering: conceiving, designing, implementing and operating

5.2 ENGINEERING ENTREPRENEURSHIP

Engineering Entrepreneurship includes by reference all of the aspects of Societal and Enterprise Context (4.1 and 4.2), all of the skills of Conceiving, Designing, Implementing and Operating (4.3 – 4.6) and all of the elements of Engineering Leadership (5.1).

In addition, there are the entrepreneurship specific skills:

5.2.1 *Company Founding, Formulation, Leadership and Organization*

Creating the corporate entity and financial infrastructure
Team of supporting partners (bank, lawyer, accounting, etc.)
Consideration of local labor law and practices
The founding leadership team
The initial organization
The board of the company
Advisors to the company

5.2.2 *Business Plan Development*

A need in the world that you will fill
A technology that can become a product
A team that can develop the product
Plan for development
Uses of capital
Liquidity strategy

5.2.3 Company Capitalization and Finances

Capital needed, and timing of need (to reach next major milestone
Investors as sources of capital
Alternative sources of capital (government, etc.)
Structure of investment (terms, price, etc.)
Financial analysis for investors
Management of finances
Expenditures against intermediate milestones of progress

5.2.4 Innovative Product Marketing

Size of potential market
Competitive analyses
Penetration of market
Product positioning
Relationships with customers Product pricing
Sales initiation
Distribution to customers

5.2.5 Conceiving Products and Services around New Technologies

New technologies available
Assessing the readiness of technology
Assessing the ability of your enterprise to innovate based on the technology
Assessing the product impact of the technology
Incremental, architectural, radical/disruptive
Accessing the technologies through partnerships, licenses, etc.
A team to productize the technology

5.2.6 The Innovation System, Networks, Infrastructure and Services

Relationships for enterprise success
Mentoring of the enterprise leadership
Supporting financial services
Investor networks Suppliers

5.2.7 Building the Team and Initiating Engineering Processes (conceiving, designing, implementing and operating)

Hiring the right skill mix
Technical process startup
Building an engineering culture
Establishing enterprise processes

5.2.8 Managing Intellectual Property

IP landscape for your product or technology
IP strategy – offensive and defensive
Filing patents and provisional patents
IP legal support
Entrepreneurial opportunities that can be addressed by technologyTechnologies that can create new products and systems
Entrepreneurial finance and organization

5.3 RESEARCH

Research builds on factors already included above, including topics in:

- **Personal and professional skills and attributes**, including topics in Attitudes, Thought and Learning (2.4), and in Ethics, Equity and Other Responsibilities (2.5)
- **Interpersonal skills**, including topics in Teamwork and Collaboration (3.1), Communication (3.2) and potentially Communications in Foreign Languages (3.3)
- **Conceiving, designing, implementing and operating systems**, including topics in Societal and Environmental Context (4.1), Enterprise and Business Context (4.2) Conceiving, Systems Engineering and Management (4.3) and System Thinking (2.3)

5.3.1 *Identification of needs, structuring and planning of research projects*

Identifying relevant research problems
Reviewing and synthesizing relevant previous work
Specifying the aims with respect to sustainability and various stakeholders' needs
Selecting research approach and methodology
Designing and structuring the project

5.3.2 *Execution of research*

Performing empirical and theoretical work
Documenting research process and findings
Analyzing results
Drawing appropriate conclusions, acknowledging limitations

5.3.3 *Presentation and evaluation of research*

Reporting the work in a coherent manuscript
Explaining what makes the work trustworthy and accurate
Relating the work with previous work
Acknowledging the work of others
Discussing implications of the work

5.3.4 *Research ethics*

Safeguarding the quality of the research
Honesty in reporting the research
Accountability for research from idea to publication
Respect for colleagues, research participants, society and environment