

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 adapt. 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.

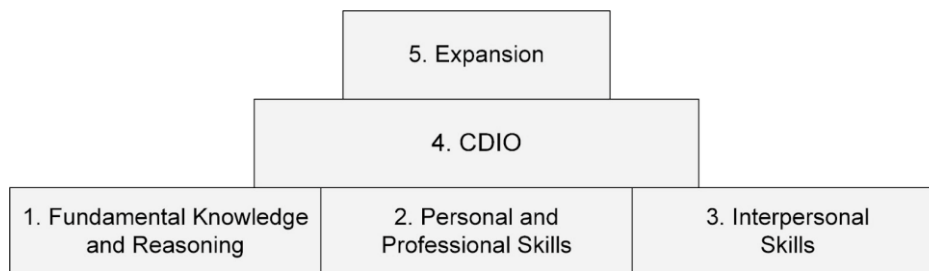


Figure 1. The four sections of the original CDIO Syllabus (Crawley, 2001) complemented with a fifth “Expansion” section in the updated CDIO Syllabus 3.0.

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) were 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 to 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 Ericsson'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 of 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 (ENAE, 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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REFERENCES

- ABET (n.a.). *Rationale for Revising Criteria 3 and 5 - Why are We Looking at Criterion 3?* Available at <https://www.abet.org/accreditation/accreditation-criteria/accreditation-changes/rationale-for-revising-criteria-3/> (accessed 12 April 2022).
- Adriole, S.J. (2018). Skills and Competencies for Digital Transformation. *IT Professional*, 20(6), pp 78-81.
- Barcelona Declaration. (2004). Conference of Engineering Education for Sustainable Development.
- Becker, C., Chitchyan, R., Duboc, L., Easterbrook, S., Penzenstadler, B., Seyff, N., & Venters, C. C. (2015). Sustainability design and software: the Karlskrona manifesto. In *IEEE International Conference on Software Engineering (ICSE)*, 2, pp. 467–476. IEEE.
- Boon, M., & Van Baalen, S. (2019). Epistemology for interdisciplinary research – shifting philosophical paradigms of science. *European Journal of Philosophy of Science*, 9 (16).
- CDIO (2004). *The CDIO Standards*. The CDIO Initiative, 12 April 2004. Available at www.cdio.org/files/standards/cdio_standards_1.0.pdf (accessed on 11 April 2022).
- Choi, B. C. K., & Pak, A. W. P. (2006). Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness, *Clin Invest Med*, 29 (6). pp 351–364.

- Chuchalin, A. (2020). Evolution of the CDIO approach: BEng, MSc, and PhD level. *European Journal of Engineering Education*, 45(1), pp. 103-112.
- Coffield. (2012). Learning Styles: Unreliable, Invalid and Impractical and yet still widely used. In Adey & Dillon (Eds.) *Bad education: debunking myths in education*. Maidenhead: Open University Press.
- Crawley, E. F. (2001). *The CDIO Syllabus – A Statement of Goals for Undergraduate Engineering Education*. Department of Aeronautics and Astronautics, Massachusetts Institute of Technology.
- Crawley, E. F., Malmqvist, J., Östlund, S., & Brodeur, D. (2007). *Rethinking Engineering Education – The CDIO Approach, 1st ed.*, Springer-Verlag, New York, USA.
- Crawley, E. F., Malmqvist, J., Östlund, S., Brodeur, D., & Edström, K. (2014). *Rethinking Engineering Education – The CDIO Approach, 2nd ed.*, Springer-Verlag, New York, USA.
- Crawley, E. F., Malmqvist, J., Lucas, W. A., & Brodeur, D. R. (2011). The CDIO Syllabus v2.0 – An Updated Statement of Goals for Engineering Education. *Proceedings of the 7th International CDIO Conference*, Technical University of Denmark, Copenhagen .
- Cruz, M.L., Saunders-Smiths, G.N., & Groen, P. (2020). Evaluation of Competency Methods in Engineering Education: A Systematic Review. *European Journal of Engineering Education*, 45(6), pp 729-757.
- De Fouw, N., Klaassen, R. & Van Der Tang, Y. (2020). Prerequisites for Interdisciplinary Learning: Organisation and Staff. *Proceedings of the 16th International CDIO Conference*, pp. 665-675, Chalmers University of Technology, Gothenburg, Sweden.
- Delors, J., et al. (1996). *Learning – the Treasure Within: Report to UNESCO of the International Commission on Education for the Twenty-First Century*, UNESCO Publishing, Paris, France.
- Edström, K., Malmqvist, J., & Roslöf, J. (2020). Scholarly Development of Engineering Education – The CDIO approach. Special Issue. *European Journal of Engineering Education*, 45(1), 1-3.
- ENAAE. (2021). *The EUR-ACE® Framework Standards and Guidelines*. <https://www.enaee.eu/wp-content/uploads/2022/03/EAFSG-04112021-English-1-1.pdf>. Accessed on April 13, 2022.
- Enelund, M., & Henricson Briggs, K. (2020). Tracks for Change, Flexibility, Interdisciplinarity and Creativity in Engineering Education. *Proceedings of the 16th International CDIO Conference*, pp. 37-47, Chalmers University of Technology, Gothenburg, Sweden.
- Enelund, M., Knutson Wedel, M., Lundqvist, U., & Malmqvist, J. (2013). Integration of Education for Sustainable Development in the Mechanical Engineering Curriculum. *Australasian Journal of Engineering Education*, 19(1), 1-12.
- EOP. (2020). The Engineering for One Planet Framework: Essential Learning Outcomes for Engineering Education.
- EU. (2018). Amended Waste Framework Directive (EU) 2018/851.
- Gunnarsson, S., Herbertsson, H., & Öрман, H. (2019). Using Course and Program Matrices as Components in a Quality Assurance System. *Proceedings of the 15th International CDIO Conference*, Aarhus University, pp 110-119. Aarhus, Denmark.
- Gurcan, F. (2019). Extraction of Core Competencies for Big Data: Implications for Competency-Based Engineering Education. *International Journal of Engineering Education*, 35(4), pp. 1110–1115.
- Ha, B. D., Trung, T. V., & Bao, N. L. E. (2019). A Proposed Closed-Loop CDIO Model to Improve the Startup Ability. *Proceedings of the 15th International CDIO Conference*, pp. 558-568, Aarhus University, Aarhus, Denmark.
- IPCC (2018). *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.).
- Junaid, S., Gorman, P. C., & Leslie, L. J. (2018). Developing Logbook Keeping as a Professional Skill through CDIO Projects. *Proceedings of the 14th International CDIO Conference*, Kanazawa Institute of Technology, Kanazawa, Japan.

- Kamp, A. (2019). *Science & Technology Education for 21st Century Europe*. Discussion paper dated 18th December 2019. Task Force CESAER, Leuven. DOI: 10.5281/zenodo.3582544
- Kamp, A. (2020). *Navigating the Landscape of Higher Engineering Education – Coping with Decades of Accelerating Change Ahead*.
- Kjellgren, B., Keller, E. & Takau-Drobin, Y. (2018). Add-on Certificate in Global Competence: A Pragmatic Answer to a Challenging Question. *Proceedings of the 14th International CDIO Conference*, pp. 748-762, Kanazawa Institute of Technology, Kanazawa, Japan.
- Klaassen, R., De Bruin, B., De Fouw, N., Kamp, A. & Hellendoorn, H. (2020). Cognitive, Social and Emotional Aspects of Interdisciplinary Learning. *Proceedings of the 16th International CDIO Conference*, pp. 701-713, Chalmers University of Technology, Gothenburg, Sweden.
- Knutson Wedel, M., Malmqvist, J., Arehag, M., & Svanström, M. (2008). Implementing Engineering Education for Environmental Sustainability into CDIO Programs. *Proceedings of the 4th International CDIO Conference*, Gent, Belgium.
- van Laar, E., van Deursen, A.J.A.M., van Dijk, J.A.G.M., & de Haan, J. (2017). The Relation between 21st Century Skills and Digital Skills: A Systematic Literacy Review; *Computers in Human Behavior*, 72, pp. 577-588.
- Linköping University. (2019). *The LiTH Syllabus*.
- Lozano, R., Merrill, M.Y., Sammalisto, K., Ceulemans, K., & Lozano, F.J. (2017). Connecting Competences and Pedagogical Approaches for Sustainable Development in Higher Education: A Literature Review and Framework Proposal. *Sustainability*, 9(10), pp.1889–1904, doi:10.3390/su9101889.
- MacLeod, M. (2018). What Makes Interdisciplinarity Difficult? Some Consequences of Domain Specificity in Interdisciplinary Practice, *Synthese*, 195, pp. 697–720.
- Malmqvist, J., Edström, K., & Rosén, A. (2020a). CDIO Standards 3.0 – Updates to the Core CDIO Standards. *Proceedings of the 16th International CDIO Conference*, pp. 60-76. Chalmers University of Technology, Gothenburg, Sweden, 2020.
- Malmqvist, J., Edström, K., Rosén, A., Hugo, R., & Campbell D. (2020b). A First Set of Optional CDIO Standards for Adoption, *Proceedings of the 16th International CDIO Conference*. Chalmers University of Technology, Gothenburg, Sweden, 2020.
- Margarov, G., & Konovalova, V. (2019). Interdisciplinary Competencies Needed for Engineers in the Digital Economy; *Computer Science and Information Technologies (CSIT)*, Yerevan, Armenia, pp. 144-147.
- Martín Núñez, J.L. & Díaz Lantada, A. (2020). Artificial Intelligence Aided Engineering Education: State of the Art, Potentials and Challenges. *International Journal of Engineering Education*, 36(6), pp. 1740–1751.
- Mathebula, M. (2018). *Engineering Education for Sustainable Development - A Capabilities Approach*, ISBN 9780367888718, Routledge.
- McDonough, W., & Braungart M. (2002). *Cradle to Cradle: Remaking the Way We Make Things*. ISBN: 9780865475878. North Point Press.
- Mejtoft, T., Berglund, S., Blöcker, C. & Cripps, H. (2020). Sustainable International Experience: A Collaborative Teaching Project. *Proceedings of the 16th International CDIO Conference*, pp. 554-563, Chalmers University of Technology, Gothenburg, Sweden.
- Mense, Evan G., et al. (2018). The Development of Global Higher Education in a World of Transformation. *Journal of Education and Development* 2(3), 47-60.
- Raworth, K. (2017). *Doughnut Economics – Seven Ways to Think Like a 21st Century Economist*. Random House Business Books.
- Mesároš, P., Mandičák, T., Mesárošová, A., & Behún, M. (2016). Developing Managerial and Digital Competencies through BIM Technologies in Construction Industry. *International Conference on Emerging eLearning Technologies and Applications (ICETA)*, pp. 217-222.
- Oberländer, M., Beinicke, A., & Bipp, T. (2020). Digital Competencies: A Review of the Literature and Applications in the Workplace. *Computers & Education*, 146, 103752.

- Osberg, D. & Biesta, G. (2020). Beyond Curriculum: Groundwork for a Non-Instrumental Theory of Education. *Educational Philosophy and Theory*.
- Passow, H.J. & Passow, C.H. (2017). What Competences Should Undergraduate Engineering Programs Emphasize? A Systematic Review. *Journal of Engineering Education*, 106(3), pp 475-526.
- Ramadi, E., Ramadi, S., & Nasr, K. (2016). Engineering Graduates' Skill Sets in the MENA region: A Gap Analysis of Industry Expectations and Satisfaction. *European Journal of Engineering Education*, 41(1), pp 34-52.
- Rist, G. (2019). *The History of Development - From Western Origins to Global Faith*. ISBN: 9781786997562. Zed Books Ltd.
- Rosén, A., Edström, K., Gumaelius, L., Högfeltdt, A.-K, Grøm, A., Lyng, R., Nygaard, M., Munkebo Hussmann, P., Vigild, M., Fruergaard Astrup, T., Karvinen, M., Keskinen, M., Knutson Wedel, M., Lundqvist, U., & Malmqvist, J. (2019). Mapping the CDIO Syllabus to the UNESCO Key Competencies for Sustainability, *Proceedings of the 15th International CDIO Conference*, Aarhus University, Aarhus, Denmark.
- Salti, H., Alkhatib, F., Soleimani, S., Abdul-Niby, M., Zabalawi, I., & Kordahji, H. (2019). Engineering education: Institutionalization, internationalisation, and graduate attributes. *Proceedings of the 15th International CDIO Conference*, pp. 20-30, Aarhus University, Aarhus, Denmark.
- Sammalisto, K., Ceulemans, K., & Lozano, F.J. (2017). Connecting Competences and Pedagogical Approaches for Sustainable Development in Higher Education: A Literature Review and Framework Proposal. *Sustainability*, 9(10), pp 1889-1904.
- Smulders, F., Kamp, A., & Fortin, C. (2018). The CDIO Framework and New Perspectives on Technological Innovation. *Proceedings of the 14th International CDIO Conference*, pp. 40-52, Kanazawa Institute of Technology, Kanazawa, Japan.
- Spelt, E.J.H., Luning, P.A., van Boekel, M.A.J.S. & Mulder, M. (2017). A Multidimensional Approach to Examine Student Interdisciplinary Learning in Science and Engineering in Higher education, *European Journal of Engineering Education*, 42(6), pp. 761-774.
- Säisä, M., Tiura, K., & Roslöf, J. (2018). Waterfall vs. Agile Project Management Methods in University-Industry Collaboration Projects. *Proceedings of the 14th International CDIO Conference*, pp. 284-292, Kanazawa Institute of Technology, Kanazawa, Japan.
- Säisä, M., Seong, T. C., Määttä, S., & Roslöf, J. (2020). International Cooperation between Two Project Learning Environments – a Case Study. *Proceedings of the 16th International CDIO Conference*, pp. 203-212, Chalmers University of Technology, Gothenburg, Sweden.
- UN. (2015). *Transforming Our World: the 2030 Agenda for Sustainable Development*, UN Resolution A/RES/70/1.
- UN. (2020). *Roadmap for Digital Cooperation – Report of the Secretary General*. June 2020.
- UN. (2021). *Sharing our Future Together – Listening to People's Priorities for the Future and Their Ideas for Action*. Concluding Report of the UN75 Office, January 2021.
- UNESCO. (2017). *Education for Sustainable Development Goals – Learning Objectives*, ISBN 978-92-3-100209-0.
- UNESCO. (2021). *Engineering for Sustainable Development*. ISBN 978-92-3-100437-7.
- van Puffelen, E., & van Oppen, M. (2020). Supporting Cross-Cultural University Education. *Proceedings of the 16th International CDIO Conference*, pp. 111-120, Chalmers University of Technology, Gothenburg, Sweden.
- Wiek, A., Bernstein, M., Foley, R., Cohen, M., Forrest, N., Kuzdas, C., Kay, B., & Withycombe, Keeler, L. (2016). Operationalising Competencies in Higher Education for Sustainable Development. In: Barth, M., Michelsen, G., Rieckmann, M., & Thomas, I. (Eds.) (2016). *Handbook of Higher Education for Sustainable Development*. Routledge, London. pp. 241-260.
- Wiek, A., Withycombe, L., & Redman, C.L. (2011). Key Competencies in Sustainability: a Reference Framework for Academic Program Development. *Sustainability Science*. 6(2), pp 203-218.
- WWF. (2020). *Living Planet Report 2020 - Bending the curve of biodiversity loss*.

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