EXPERIENCES FROM APPLYING THE CDIO STANDARD FOR SUSTAINABLE DEVELOPMENT IN INSTITUTION-WIDE PROGRAM EVALUATIONS

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ABSTRACT

In the CDIO standards 3.0, the original "core" CDIO standards have been updated regarding sustainable development. In addition, one of the new, so called "optional", CDIO standards addresses sustainable development. This paper puts the new CDIO standard for sustainable development to test, in an institution-wide evaluation of engineering education programs at the KTH Royal Institute of Technology. First, the standard is operationalized by establishing a set of indicators and slightly modifying the standard rubrics. Then, it is used in the evaluation of a large number of programs on bachelor and master level. Examples are given of the evaluation outcomes, and the character of the integration of sustainable development in programs on different rubric levels are discussed. With the proposed indicators and rubric modifications, the new standard is concluded to be a useful tool for evaluating, promoting, and guiding, integration of sustainable development, not only in programs with particularly high ambitions regarding sustainable development, but in basically any engineering program. It is recommended that the new standard, with the here proposed modifications, is used for setting university-wide goals and for providing teachers and program directors with a framework for enhancing the future relevance of engineering education programs.

KEYWORDS

Engineering education for sustainable development, Program evaluation, Optional standard for sustainable development, Standards: 1-12

INTRODUCTION

The CDIO standards 3.0 comprises updates to the 12 CDIO standards together with the introduction of "optional" standards, one of which refers to integration of sustainable development in engineering programs. When the new standards were first presented, the CDIO community was encouraged "*to document the work and share their experiences, in particular reflecting on the usefulness of the new standards for future refinement and development*" (Malmqvist et al 2020a). The objective of this paper is, accordingly, to analyse the first experiences of using the new CDIO standard for sustainable development in institution-wide program evaluations at the KTH Royal Institute of Technology. In the process of evaluating the integration of sustainable development within nearly one hundred engineering programs, the standard has been operationalized and developed in further detail.

The paper is structured as follows. First, the new standard for sustainable development is presented as it was established in 2020 (Malmqvist et al., 2020a). Next, we briefly present the national and institutional context for integration of sustainable development in engineering education at KTH, and the institution-wide evaluation of programs. Thereafter follows a section describing how the new CDIO standard for sustainable development was refined and operationalized, to better capture conceptual distinctions as well as essential differences in how programs had implemented sustainable development. The results of the evaluation are illustrated with 15 programs as examples. Finally, we analyse these experiences and formulate recommendations on how to update and apply the standard.

THE NEW CDIO STANDARD FOR SUSTAINABLE DEVELOPMENT

The CDIO standards were first formulated in 2004 (CDIO 2004) and presented more extensively in Crawley et al. (2007). They define the distinguishing features of CDIO programs in terms of a set of principles and good practices concerning: engineering education philosophy and aims (Standard 1); curriculum development (Standards 2, 3, 4); engineering projects and workspaces (Standards 5, 6); teaching and learning methods (Standards 7, 8); faculty development (Standards 9, 10); and assessment and evaluation (Standards 11, 12). The standards are intended to serve as guidelines for educational reform, enable benchmarking with other CDIO programs, and provide a tool for self-evaluation-based continuous improvements.

In 2014 and 2016, minor modifications resulted in the CDIO standards 2.0 (Crawley et al. 2014) and 2.1 (Bennedsen et al. 2016). In 2017, Malmqvist et al (2017) pointed out needs for more extensive updating of the standards to account for a number of education change drivers, both external and internal within the CDIO Initiative. This eventually resulted in the CDIO standards 3.0, where the original twelve, now called “core”, CDIO standards have been substantially updated (Malmqvist et al 2020b) and also complemented with so called “optional” CDIO standards that codify additional educational good practices that have been developed within the CDIO community (Malmqvist et al 2020a).

One of the major change drivers, motivating and guiding the updating of the standards, has been the recognition that engineering education plays a critical role in the urgent societal transformations that are needed for ensuring a healthy planet and sustainable living conditions for ourselves as well as for future generations (e.g. NAE 2008, Enelund et al 2013, UN 2015, UNESCO 2017). The importance of and focus on sustainability and sustainable development has therefore been emphasized in several of the updated twelve “core” CDIO standards. For example, in Standard 1 the word “sustainable” has been added in the characterization (*Adoption of the principle that sustainable product, process, system, and service lifecycle development and deployment … are the context for engineering education*), and in the description of Standard 1 environmental, social, and economic sustainability are expressed to be considered as integral aspects throughout the lifecycle (Malmqvist et al 2020b). Sustainable development is hereby from now on explicitly an integral part of the CDIO concept. To further emphasize the role of sustainable development, and to provide goals and guidance for programs with particularly high ambitions, one of the new “optional” CDIO standards addresses sustainable development (Malmqvist et al 2020a).

In Box 1-4 below, this new CDIO standard for sustainable development – hereafter referred to as ‘*the SD standard’* – is reproduced as it was established (Malmqvist et al., 2020a). It follows the same format as all CDIO standards and is formulated in terms of: a characterization; a description; a motivating rationale; and rubrics for self-evaluation.

As seen in the description in Box 2, the SD standard is formulated with direct reference to the twelve "core" standards, pointing out how the central aspects of the "core" standards should be complemented with elements from the education for sustainable development domain (ESD), such as *interdisciplinarity and transdisciplinarity*, *transformative learning*, and *key competences for sustainability* (e.g., according to UNESCO 2017). The SD standard can hereby, more than other "optional" or "core" standards, be considered as a kind of meta-standard that guides and has impact on the implementation of all twelve core standards.

The general principles and functions of the CDIO standard rubrics are described by Bennedsen et al (2014; 2016). As seen in Box 4, the rubrics for the SD standard goes slightly beyond these general principles in that they are more detailed in the description of evidence and indicators for the different rubric levels. This, among other things, will be further elaborated in the following section, where the SD standard is put to test in program evaluations.

Box 1. The SD standard characterization.

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

Box 2. The SD standard description.

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

Box 3. The SD standard rationale.

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

Box 4. The SD standard rubric.

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

APPLICATION OF THE CDIO STANDARD FOR SUSTAINABLE DEVELOPMENT IN PROGRAM EVALUATIONS AT KTH

Evaluating integration of sustainable development according to national and institutional mandates

According to the Swedish Higher Education Act, Swedish higher education institutions *shall promote sustainable development in their activities, which means that current and future generations are assured of a healthy and good environment, economic and social welfare, and justice*. Further, the Swedish Higher Education Ordinance stipulates overarching learning objectives and degree requirements for all Swedish university degrees. For some degrees, for example the Master of Science in Engineering degree (*civilingenjörsexamen*), there are specific degree requirements regarding sustainable development, whereas some degrees, for example the general Bachelor of Science and Master of Science degrees, do not have degree requirements directly related to sustainable development.

In addition to these national requirements, many universities have formulated their own internal sustainability objectives. For example, in the internal sustainability objectives for education for the period 2016-2020 for the KTH Royal Institute of Technology, it is stated that: *Sustainable development shall be integrated into all educational programs at all levels so that students can contribute to the sustainable development of society after graduation* (KTH). KTH is hereby going beyond the national policies by also requiring integration of sustainable development in the general Bachelor of Science and Master of Science programs and in the third level PhD programs.

The overall KTH approach for considering sustainable development in the engineering education programs is very much in line with the CDIO concept of integrated curriculum (Standard 3), in the meaning that sustainable development should not just be considered as an add-on in some separate courses but instead be interwoven with the learning of disciplinary knowledge and its application in professional engineering. How this should be implemented is however left for the programs to decide but guidelines and support is provided by the KTH Sustainability Office and the KTH Department of Learning.

During 2020, the fulfilment of KTH's sustainability objectives for education for the period 2016-2020 has been evaluated by the KTH Sustainability Office and the KTH Department of Learning in collaboration. Nearly 100 programs on bachelor, master, and doctoral level, were evaluated. Due to the large number of programs, the basis for the evaluation was limited to program objectives and intended learning outcomes stated in the formal program and course documents, together with the yearly program analysis reports that each program director produces as part of the KTH quality assurance procedures. This limits the evaluation, and the results should be interpreted accordingly.

As the SD standard is new since the summer 2020 (Malmqvist et al 2020a), it has not yet been used to develop the KTH programs. Still, it was decided to apply the new SD standard as one of several instruments in the evaluation of the fulfilment of KTH's sustainability objectives for education for the period 2016-2020.

Operationalizing the SD standard

To facilitate the application of the SD standard in the evaluation of KTH's engineering programs, a number of indicators were established, see Box 5. The indicators relate to different elements in the SD standard description (Box 2) and rubrics (Box 4).

The first indicator (i) considers the extent and character of the program objectives. The Swedish Higher Education Ordinance sustainable development related degree requirements for the Master of Science in Engineering degree (*civilingenjörsexamen*), here reproduced in Box 6, were used as benchmark for all programs (i.e., also for the general Bachelor of Science and Master of Science programs for which the Higher Education Ordinance does not stipulate any specific sustainable development related requirements). The second indicator (ii) considers the introduction to sustainable development at an early stage of the program. This is considered important for building progression through following courses, and also for avoiding that the basic concepts of sustainable development are being repeated again and again through the program.

The three next indicators (iii-v) refer to the number of courses in the program that include learning experiences related to sustainable development. It should be noted that only *compulsory* courses that all students in the program must take, are considered. Just like in the SD standard rubrics (Box 4) distinctions are made between *minor* and *substantial* sustainable development related learning experiences, as well as between courses that are mainly developing students' *knowledge* about sustainable development, and courses that are developing students' *knowledge & skills*, and *key competencies for sustainability*. To facilitate the application of the SD standard in the evaluation of KTH's programs, the meaning of *minor* and *substantial* have here been more clearly defined, see Box 7.

The last indicator (vi) considers the program's development plans and processes as reflected in the program analysis reports. This can for example be plans for integrating sustainable development in more courses, or clarifying and improving progression between courses, or enhancing the teachers' competences.

We note that indicators iii-v can be determined quantitatively whereas indicators i, ii, and vi will have to be judged qualitatively. The feasibility of the indicators will be further explored and discussed below.

Box 5. Proposed indicators for application of the SD standard in program evaluations.

Indicator		Value
i	Sustainable development (SD) related program objectives	0: missing; 1: some; 2: in line with the Swedish Higher Education Ordinance requirements for the Master of Science in Engineering Degree; 3: more extensive/ambitious.
ii	Introduction to SD at an early stage of the program	0: missing; 1: exists; 2: extensive/ambitious.
iii	Number of compulsory courses with *minor* SD learning experiences	Number
iv	Number of compulsory courses with *substantial* SD learning experiences that are developing students' *knowledge* for SD	Number
v	Number of compulsory courses with *substantial* SD learning experiences that are developing students' *knowledge & skills* for SD	Number
vi	Development plans & processes	0: missing/unclear; 1: exists; 2: extensive/ambitious.

Box 6. Sustainable development related degree requirements for the MSc in Engineering degree (*civilingenjörsexamen*), as stipulated in the Swedish Higher Education Ordinance.

For the Master of Science in Engineering degree, the student should be able to demonstrate:

- ability to design and develop products, processes and systems with consideration of human prerequisites and needs and the society's goals for economically, socially and ecologically sustainable development;
- ability to formulate judgements considering relevant scientific, societal and ethical aspects, and demonstrate an awareness of ethical aspects on research and development work;
- insight into the possibilities and limitations of technology, its role in society and the responsibility of humans for its use, including social, economic as well as environmental and work environment aspects.

EVALUATION PROCESS AND RESULTS

Testing and calibrating the indicators and rubrics in pilot evaluations

The application of the SD standard in the evaluation of the KTH programs was performed in two steps. First, a pilot was performed with ten selected programs. This confirmed the feasibility and enabled some calibration of the indicators and definitions, described in Box 5-7. As mentioned in the previous section, the SD standard rubrics (Box 4) goes slightly beyond the general CDIO standards rubrics principles, in that they are more detailed in the description of evidence for the different rubric levels. These details were found particularly useful, since they make the rubrics applicable, not only for evaluating program development towards full implementation of the SD standard according to the description (Box 2), but also for evaluating and guiding development of basically any engineering program with whatever ambitions and goals regarding sustainable development.

Based on the experiences from the pilot evaluations, the SD standard rubrics were further elaborated to better capture conceptual distinctions as well as essential differences in how programs are integrating sustainable development. This resulted in the slightly modified set of rubrics in Box 8, where bold text indicates additions/changes in relation to the original

formulations in Box 4. Most modifications are calibrations of the number and character (*minor* or *substantial*) of sustainable development learning experiences on the different levels. Also, '*skills*' has been added on level 3 and '*key competencies for sustainability*' has been added to level 4. The motivation for and feasibility of these modifications will be further discussed below.

Box 7. Proposed definitions of some terms and concepts in the SD standard.

Minor vs. *substantial* learning experiences:

- A *minor* sustainable development (SD) learning experience is typically a small SD related module, and related learning outcomes and assessment, integrated in a core engineering course or in a program introductory course, corresponding to about one ECTS credit.
- A *substantial* SD learning experience can either be a course that is more or less completely dedicated to SD, or extensive integration of SD in a core engineering course in terms of several intended learning outcomes and related learning activities and assessment, corresponding to several ECTS credits.

Knowledge, *skills*, and *key competencies* for sustainability:

- The modified rubric level 3 (Box 8) requires substantial SD learning experiences that, in addition to developing students' *SD knowledge*, also develop students' *SD skills*, i.e., abilities to apply and operationalize their SD knowledge in engineering work; evaluate environmental, social and economic impacts; and take action for sustainable development based on such evaluations for example in engineering decision making and engineering design.
- The modified rubric level 4 (Box 8) further requires development of students' *key competencies for sustainability*, for example systems-thinking, critical-thinking, normative competency, and abilities to communicate and collaborate across disciplinary and cultural borders. These competencies are clusters of individual dispositions comprising knowledge, skills, motives, and attitudes, that within the Education for Sustainable Development (ESD) domain are considered necessary for coping with the increasingly diverse and interconnected world and for contributing to sustainable development (e.g., Wiek et al 2016, UNESCO 2017, Rosén et al 2019, Brundiers et al 2021).

Box 8. The SD standard rubric with proposed modifications (in bold).

0 – There are no sustainable development learning experiences in the program. [No modifications proposed]

1 – Minor sustainable development learning experiences **are** implemented **in at least one course** and needs and opportunities for extended integration of sustainable development have been identified.

2 – At least **two sustainable development learning experiences, where at least one is substantial, are** implemented and there is a plan for extended integration of sustainable development.

3 – There are explicit program goals and intended learning outcomes **considering knowledge as well as skills** related to environmental, social, and economic aspects of sustainability, and **students learning towards these goals and outcomes are supported by** at least **four sustainable development learning experiences, where at least two are substantial**, including an introduction early in the program.

4 – The integration of sustainable development is pervasive, well adapted to the program context, promoting progression of knowledge, skills**, attitudes, and key competencies for sustainability**, and there is documented evidence that students have achieved the related intended learning outcomes.

5 – Sustainable development is fully integrated in accordance with the description in the optional CDIO standard for sustainable development. [No modifications proposed]

Evaluation results

After the pilot phase followed a full evaluation of a large number of first and second level programs using the calibrated indicators and definitions (Box 5-7) and the modified rubrics (Box 8). The evaluation results for 15 programs are shown in Table 1. All these examples are from the first 3 years of Master of Science in Engineering programs (the bachelor part of integrated 5 year or "3+2" programs). The shaded column (second from the right) displays the judged SD standard rubric level, based on the indicator values in the preceding columns. The proximity to the next rubric level is estimated in the rightmost column (0=far from; 1=on the way, 2=close). As seen, all these programs have been judged to be on rubric level 1 or higher, which means that they have all integrated sustainable development (SD) to some extent.

Table 1. Examples of the evaluation outcome for 15 KTH programs.

Program	i) Program objectives (0-3)	ii) Introduction to SD at an early stage of the program (0-2)	iii) Number of compulsory courses with minor SD learning experiences	iv) Number of compulsory courses with substantial SD learning experiences that are developing students' knowledge for SD	v) Number of compulsory courses with substantial SD learning experiences that are developing students' knowledge & skills for SD	vi) Development plans & processes (0-2)	SD standard rubric level (0-5)	Proximity to the next SD standard rubric level (0-2)
A	2	2	6	0	4	0	3	2
B	2	2	4	1	1	0	3	1
C	3	0	5	1	0	0	2	1
D	2	1	4	0	1	0	2	1
E	1	1	1	0	0	2	1	2
F	2	1	1	1	0	2	2	1
G	1	0	0	0	1	1	1	2
H	1	0	1	0	1	1	2	1
I	3	2	2	0	1	0	2	1
J	3	1	3	0	0	0	1	1
K	3	1	3	0	0	2	1	1
L	3	2	3	0	3	2	3	2
M	3	2	1	4	0	2	2	2
N	2	0	1	0	0	1	1	0
O	2	1	3	0	0	1	1	0

Among the programs judged to be on rubric level 1, there are quite some differences in the way SD is integrated. Program G for example has only one, but *substantial*, SD learning experience in terms of a 7.5 ECTS course that is completely dedicated to SD issues and aspects of the core discipline of the program and related professions. Program O has three *minor* SD learning experiences integrated in three different core disciplinary courses. Program E only has one *minor* SD learning experience that is formalized in terms of intended learning outcomes and assessment. In the program analysis report, this program however describes ambitions and plans to enhance several existing SD related learning activities and formalize corresponding intended learning outcomes and assessment. This program is therefore judged to be very close to reach rubric level 2 as indicated in the rightmost column. This situation

reflects a general evolution process for many programs, where engaged informal bottom-up initiatives creates informal SD related learning activities which are eventually formalized and then work as drivers for more systematic enhancement and progression of SD learning through the program.

As stated in Box 8, a distinction between rubric levels 1 and 2 is, that to be on level 2 a program must have at least two SD learning experience where at least one is *substantial*. As seen in Table , most programs judged to be on level 2 have one *substantial* SD learning experience and one or several *minor* SD learning experiences. The *substantial* SD learning experiences are here typically 6 or 7.5 ECTS courses which are more or less completely dedicated to SD issues and aspects of the core discipline of the program and related professions. In contrast to the other programs on level 2, program M has as many as 4 *substantial* SD learning experiences. The reason why this program is still not judged to be on a higher rubric level, is that all these *substantial* SD learning experiences mainly considers development of the students' *knowledge* about SD, but there are no or limited opportunities for the students to develop *skills* and abilities for actually *doing* SD.

A general observation from the program evaluations is that sustainability-related learning objectives in most courses are formulated in terms of "know", "describe", "explain", "reason about", "define", "discuss", "reflect on", which hence can mainly be categorised as *knowledge & understanding* and to some extent also *values & attitude*. There are therefore obvious needs for many programs to develop courses with learning objectives, and associated learning activities and forms of assessment, which also address *skills* and *abilities to develop and design sustainable products, processes, systems and services*, and also other skills and abilities that can contribute to sustainable development. These needs are reflected by indicator v, and a distinction between rubric levels 2 and 3 is that a program for being judged on level 3 must have *substantial* SD learning experiences that are developing students' *knowledge & skills* for SD (see Box 8). These needs were also the motivation for adding '*skills*' already on level 3 in the here proposed modified SD standard rubrics in Box 8 (compared to the original rubric formulations in Box 4 where 'skills' were not required before level 4). As seen in Table , the three programs that are judged to be on level 3 respectively have one, three, and four, *substantial* SD learning experiences that are developing students' *knowledge & skills* for SD. Such courses are typically project-based, or at least includes some kind of project or extensive exercises and assignments, where the students are to apply SD related knowledge and methods in realistic contexts and tasks. To reach rubric levels 4 and 5 will require more extensive implementation of project-based or challenge-driven learning experiences (e.g., Wiek et al 2014, Högfeldt et al 2019, Rådberg et al 2020) that can develop students' key competencies for sustainability. Such learning experiences are currently rare on the bachelor level but found in some master programs.

It should here again be emphasized that this evaluation, and the results in Table , are limited in terms of the scope of the documentation that was analysed. Further, the evaluation only considered compulsory courses during the first three years, also excluding the thesis project. We note that the thesis project can provide an excellent opportunity for a student to develop skills and abilities for SD, if appropriately considered in intended learning outcomes, assessment, and grading. Nevertheless, the thesis project is individual, and the evaluation results reflect the educational experience afforded to *all students*. We further note that there are compulsory courses in many programs with more limited and informal awareness building learning activities related to SD and also elective courses with strong formal integration of sustainable development, which are not indicated in this evaluation but nevertheless provide valuable contributions to students' SD learning.

CONCLUSIONS & DISCUSSIONS

The concept of "optional" CDIO standards is new and the role and function of these standards still remains to be explored. However, with the here proposed modifications of the rubrics and the introduced indicators and definitions, a conclusion from this work is that the "optional" CDIO standard for sustainable development is now a useful tool for evaluating the integration of sustainable development in engineering education programs. We have further demonstrated that the SD standard is useful not only for guiding and evaluating program development towards full implementation of the standard, but also for evaluating, promoting, and guiding integration of sustainable development in basically any engineering program.

Integration of sustainable development is crucial for the development of future engineering education (e.g., Gumaelius and Kolmos, 2020). It is often initiated and driven as bottom-up initiatives by engaged teachers and program directors, but it should be emphasized that a key factor for more extensive and systematic integration of sustainable development in higher education institutions is the commitment of top management (e.g., Leal Filho et al, 2017, Lozano et al, 2015). Key aspects are that top management sets goals for the integration of sustainable development and also makes sure that there are mechanisms for following up the extent to which the goals are reached (Finnveden et al, 2019). We suggest that the SD standard can be used for setting university-wide goals. A relevant goal for a technical university could for example be that all engineering programs should reach rubric level 3 (according to the here proposed modified rubrics) and that there should be some programs that reaches levels 4 and 5. By defining the goals in this way and operationalizing the SD standard, teachers and program directors are provided with a framework for dialogue and collaboration on the integration of sustainable development in their programs, and there is also a format for follow-up.

Although the SD standard was developed for engineering education programs, it could probably be applied for education programs in other disciplines as well. This is important since sustainable development needs to be integrated broadly across different disciplines (Finnveden and Schneider, 2019). It is therefore suggested that the SD standard, with the here proposed modifications, should be used and further tested not only by technical universities but also more broadly. This could pave the way for inter- and trans-disciplinary interactions and more fundamental transformations of our educational systems and society.

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