RELEVANCE OF CDIO TO INDUSTRY 4.0 – PROPOSAL FOR 2 NEW STANDARDS

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ABSTRACT

This is a paper meant for discussing if the CDIO Framework remains relevant today, considering the manufacturing landscape which is broadly captured under the umbrella of Industry 4.0. It explores if the 12 CDIO Standards need to be expanded to include additional standards. This paper can be broadly divided into 2 parts. The first half of the paper begins with a brief explanation of what Industry 4.0 is, and the key elements such as Internet of Things (IoT), cloud computing, big data and data analytics, and cyber-physical system (CPS). Then, based on the reviews of available publications to date, the paper summarises the implication of Industry 4.0 on the knowledge needed and skill profile of future engineering graduates. This first half concludes with a discussion of how Education 4.0 – the educational 'counterpart' of Industry 4.0 – will affect the learning experience. The second half of the paper reviews the relevance of the CDIO Syllabus in terms of its coverage of knowledge and skills needed for Industry 4.0; followed by the review of the CDIO Standards. Each Standard is studied in relation to its applicability to Industry 4.0. This paper suggests that the CDIO Syllabus be retained in its current format but recommends that one uses a Skills Profile approach when validating the skills and attributes with key stakeholders. The paper also concludes that the CDIO Standards are still relevant as their descriptions can be expanded to reflect the coverage of Industry 4.0. However, to better serve the educational needs of Industry 4.0, this paper proposes that two additional standards be introduced: one on Industry Engagement, and another on Workplace Learning.

KEYWORDS

Engineering Education, Industry 4.0, Internet of Things, CDIO Syllabus and Standards

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called "courses". A teaching academic is known as a "lecturer", which is often referred to a as "faculty" in the universities.

INTRODUCTION

The main role of the 12 CDIO Standards is to serve as a guideline for educational program reform and evaluation, create benchmarks and goals with worldwide application, and provide a framework for continuous improvement. Recently, Malmqvist, Edstrom & Hugo (2017) proposed a set of 7 potential optional standards, which are suggested for a more advanced or broadened competence. The authors made it clear that the intent is to stimulate discussion to the use of CDIO as framework for redesigning engineering curriculum. They noted that the proposal "should be considered as first drafts, to be further evaluated and refined through discussions in the CDIO Initiative prior to acceptance." Earlier, Campbell & Beck (2010) had suggested a standard on internationalization and mobility, but was not accepted at that time.

This paper aims to contribute to that discussion. The key difference in our approach here is that we based our reviews on the continued relevance of the existing 12 standards and the syllabus in relation to the new manufacturing landscape broadly captured under the umbrella of Industry 4.0. In particular, we strive to re-interpret the applicability of the existing 12 Standards by viewing them through the lens of Industry 4.0 in meeting the competencies required in Industry 4.0. Our approach is to first carry out review of available publications on the impact of Industry 4.0 on engineering education, and the approach to redesign the engineering curriculum. To this end, we search the Internet using Google Scholar and ScienceDirect. One observation we noted is the lack of publications on educational response to Industry 4.0. Motyl, et al (2017) had noted that currently there are limited studies in engineering education on the educational needs of students. Likewise, Lu (2017) reported of limited systematic and extensive review of recent research on Industry 4.0. As such, this work made references to mostly white papers and reports produced by consulting companies, supported by relevant journal papers and conference presentations.

WHAT IS INDUSTRY 4.0?

Industry 4.0, or "Smart Industry", or "Smart Manufacturing", or the Fourth Industrial Revolution, comprising a confluence of trends and technologies, promises to reshape the way things are manufactured. It started in 2011 in Germany as "Industrie 4.0": an initiative comprising representatives from business, politics, and academia to strengthen the competitiveness of the German manufacturing industry. Industry 4.0 represents a paradigm shift from "centralized" to "decentralized" production, made possible by technological advances which constitute a reversal of conventional production process logic. Simply put, it means that industrial production machinery no longer simply "process" the product, but that the product communicates with the machinery to tell it exactly what to do (GTAI, 2014). The major consultancies tend to define Industry 4.0 to suit their approach of assisting clients make transition from current manufacturing conditions to that of Industry 4.0. While there are broad agreements in terms of its underlying principles such as interoperability virtualization, decentralization, modularity (Hercko & Hnat, 2015), each consultancy appear to have its own interpretation of that components made up Industry 4.0. This is perhaps not entirely surprising. As noted by Pereira & Romero (2017), despite the increased attention on Industry 4.0 by various sectors, the concept remains non-consensual.

From the author's point of view, and for the purpose of this paper, it is more important to understand the wider implications that Industry 4.0 can affect engineering education, based on the way it impacted the manufacturing industries. It is claimed that companies that adopted Industry 4.0 to transform their manufacturing processes stands to benefit from its many advantages including much greater efficiency, agility and mix in a production without sacrificing quality, cost, or speed; to allow a company to innovate more rapidly and gain greater revenues. However, while progress had been made by some manufacturers, many others are still holding back. Many of the examples in Industry 4.0 appears to be related to process automation in the manufacturing sector (VDMA, 2016; McKinsey, 2017). Indeed, it was noted that while most manufacturers are certainly investing into Industry 4.0 capabilities and technologies, few have achieved the scale and integration required to drive enterprise value from Industry 4.0 (KPMG, 2017). Among the implementation barriers identified, are: lack of necessary talent and challenges with integrating data from disparate sources in order to enable Industry 4.0 applications (EEF, 2016; McKinsey, 2016). These are the areas where engineering education can play a big role in preparing the right type of graduates needed.

INDUSTRY 4.0: WHAT ARE THE KNOWLEDGE AND SKILLS NEEDED?

While domain knowledge remains important, engineers of tomorrow need to also be acquainted with key elements that make up Industry 4.0, which include the Internet of Things (IoT), cloud computing, big data and data analytics, and cyber-physical system (CPS). Again, different consultancies interpret these differently, and an example from one of them is shown in Figure 1. The main idea of the concept is the interconnectivity of production machinery, machined products and semi-finished products and all other systems and subsystems of an industrial enterprise.

For the interest of the wider audience, the following paragraphs briefly describe some of these technologies, as distilled from various publications reviewed.

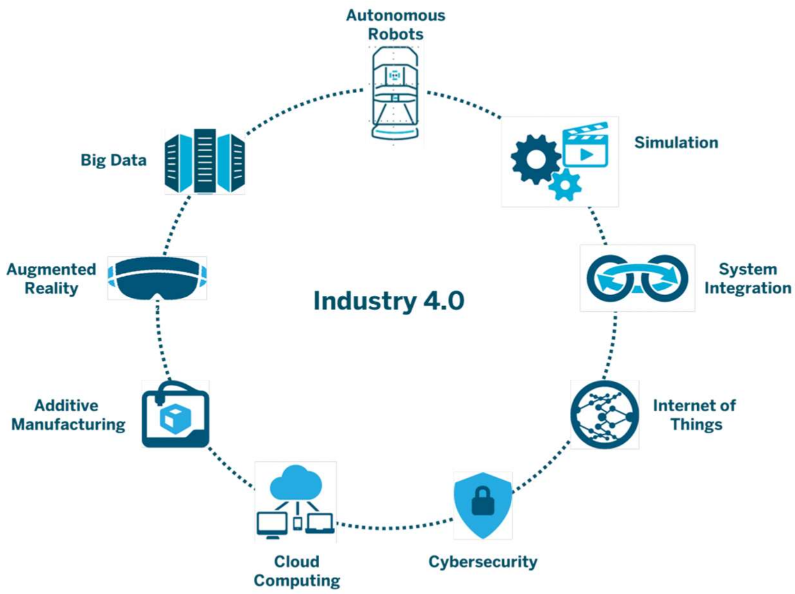

Figure 1. Industry 4.0 and enabling technologies (Source: www.aethon.com)

IoT describes a system where items in the physical world, and sensors within or attached to these items, are connected to the Internet via wireless and wired connections. Each sensor will monitor and collect data on a specific condition such as location, vibration, motion, temperature and other parameters. These sensors can use various types of local area connections such as RFID, Wi-Fi, Bluetooth, etc. Sensors can also have wide area connectivity such as GSM, 3G, and LTE. IoT can connect both inanimate and living things, and change the types of item communicate over a network. With IoT all equipment will have the ability to communicate, share information about their condition and the surrounding environment with people, software systems and other machines. This information can be shared in real-time or collected and shared at defined intervals. Going forward, everything will have a digital identity and connectivity, which means you can identify, track and communicate with objects.

Closely related to IoT are digitization, big data, cloud computing and data analytics. Digitization is the process of converting data from the sensors into a digital format. Digitizing data makes it easier to preserve, access, and share. Big data is a term that describes the large volume of data characterized by volume, velocity, variety, variability and complexity – both structured and unstructured – that inundates a business on a day-to-day basis. The most important thing is what organizations do with the data that matters. Cloud computing, simply put, is the delivery of computing services – servers, storage, databases, networking, software, analytics, and more – over the Internet ("the cloud"). Cloud computing and IoT both serve to increase efficiency in our everyday tasks, and the two have a complimentary relationship: IoT generates massive amounts of data, and cloud computing provides a pathway for that data to travel to its destination. Data analytics refers to qualitative and quantitative techniques and processes used to convert big data into actionable insights that enhance productivity and produce business gain. Data analytics can help generate meaningful production management information that aid decision-making, e.g. make sense of market developments and customer behaviour to improve products and develop new products and services, improve operations, etc (BCG, 2015; Deloitte, 2015).

CPS are enabling technologies which bring the virtual and physical worlds together to create a truly networked world in which intelligent objects communicate and interact with each other. CPS provide the basis for the creation of an IoT, which combines with the Internet of Services to make Industry 4.0 possible. They permit multiple innovative applications and processes a reality as the boundaries between the real and virtual worlds disappear. As such, they promise to revolutionize our interactions with the physical world in much the same way that the internet has transformed personal communication and interaction.

Industry 4.0 is transforming the future of work, creating far-reaching impact on jobs, ranging from significant job creation to job displacement, and from heightened labour productivity to widening skills gaps (WEF, 2016). Existing jobs are also going through a change in the skill sets required to do them. It will create disruptions in the labour market by eliminating some of the low-skilled and/or repetitive jobs, at the same time increasing the shortage of talented and highly-skilled workers (BCG, 2015). Entire manufacturing processes will change, and so is the interaction between human workers and the machines and processes. Such transformation came about as a result of two trends (ISRA & Acatech, 2013): Firstly, traditional manufacturing processes characterised by a very clear division of labour will now be embedded in a new organisational and operational structure where they will be supplemented by decision-taking, coordination, control and support service functions. Secondly, it will be necessary to organise and coordinate the interactions between virtual and real machines, plant control systems and production management systems. There is now convergence of info-communication technologies, manufacturing and automation technology and software.

What about skills needed to realise the objectives of Industry 4.0? Most literatures tend to focus on the benefits of adopting Industry 4.0; and many consultancies are offering advice on the approach to bring out the necessary transformation in business practices to reap the benefits. What are the skills needed and how to develop them are not clear. The next paragraph provides a brief summary of the literatures on skills suggested for Industry 4.0.

Javier (2015) for example, highlighted 4 skills that will help engineers compete and deliver in an age of smart manufacturing*:* systems thinking, data savviness, collaboration and communication, and adaptability. Focusing on robotics and automation, Richert et al (2016) suggested that the needed soft skill competencies will be the ability to solve problems by virtual teamwork and to be able to work in hybrid teams consisting of human and robots, working indispensable together. Benesova & Tupa (2017) suggested qualifications and skills needed for 2 job profile: IT and Production. VDI & ASME (2015) suggested a tiered approach to derive qualifications and skills needed for the factory worker of the future. ILO (2014) suggested using technology foresights for identifying future skills needs and proposed a methodology for skills needs prognosis based on technology roadmaps. KPMG (2016) noted that, since many disciplines are needed for Industry 4.0, a profiling approach based on the convergence of (1) Theoretical knowledge and expertise, (2) Hardware skill, and (3) Software and algorithm skills, would be suitable, as shown in Figure 2. Indeed, technological advancement brought about by Industry 4.0 is impacting all disciplines, economies and industries, perhaps none more so than production, including how, what, why and where individuals produce and deliver products and services (WEF, 2017).

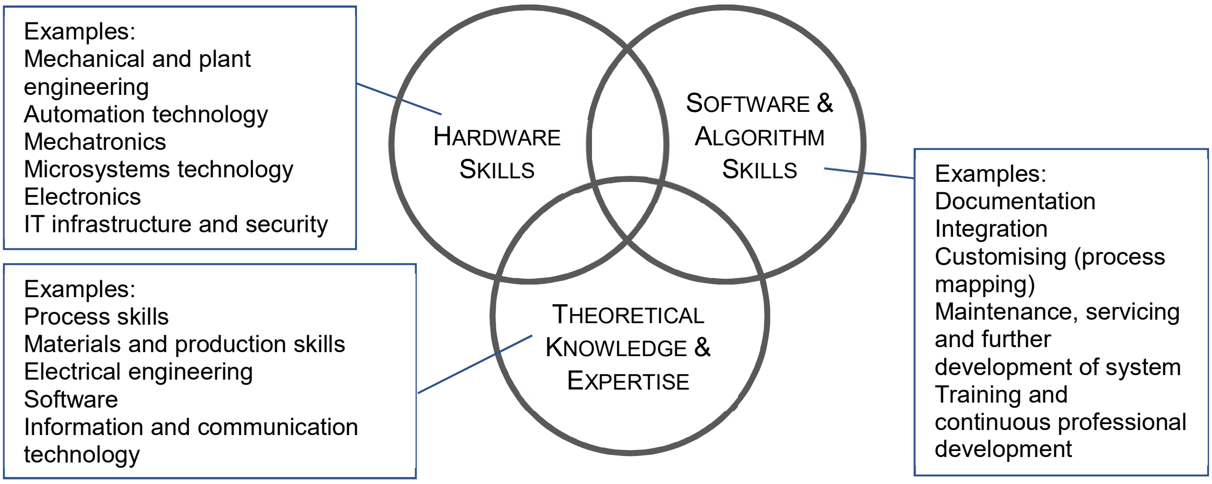

Figure 2. Industry 4.0 Skill Profile (Adapted from KPMG, 2016)

EDUCATION 4.0 – HOW WILL INDUSTRY 4.0 AFFECT ENGINEERING EDUCATION?

Industry 4.0 needs to be supported by Education 4.0: educational institutions need to rethink existing ways of educating learners and how to encourage life-long learning in order to succeed in this latest round of industrial revolution. It can be expected that Industry 4.0 will affect engineering educational systems in the most fundamental ways, including how students are currently engaged. Education is increasingly becoming “just in time” rather than “just in case” (Brophy, 1993): it is more about what you need to know for a certain time than compiling knowledge that may never be needed. Data regarding student performance, behaviour, development, and interaction inside classrooms and online platforms can offer valuable opportunities to improve the learning process. The ability of higher education institutions to leverage on data analytics to exploit such data to produce useful insights would result in intelligent decisions with regards to the delivery of customized education and personalized learning experience for students. The learning cycle will also be affected, for example, shorter in-campus learning to make room for longer internship without extending program duration.

Educational institutions will need to offer more short courses, targeting at adult learners seeking new knowledge and skills as part of lifelong learning and as preparation for career advancement. It is highly unlikely that employees will get days-off for long duration to attend lessons full-time (e.g. a semester) in classrooms for a whole semester as per current academic calendars. Shift workers will certainly pose additional challenges. Successful skills development for Industry 4.0 cannot be delivered solely through “traditional” training and professional development formats such as face-to-face learning. It increasingly requires the use of new digital formats targeted at specific learner groups and needs. It can be anticipated that greater usage of blended classroom and immersive virtual learning environments (VLEs) will be the norm. All these in turn, will change the way teaching is done, and how teachers are trained, especially in their digital literacy, which include not only the design of VLE but also in digital coaching and virtual collaborations (Richert, et al, 2015).

Lastly, we noted that a key component in engineering education is project work. Projects in Industry 4.0 will be increasingly complex and multi-disciplinary in nature. For example, the innovation and development of CPS will require computer scientists and network professionals to work with experts in various disciplines as well as in globalized contexts (Richert, et al, 2016). Students need to be more proficient in interpersonal skill, in working with people with different background and disciplines from their own. The Learning Factory concept, originally introduced in 1994 (Abele, et al, 2015), is now gaining popularity as a way to teach students about working under the Industry 4.0 environment (Baena, et al, 2017; Erol, et al, 2016).

From the above discussion it is clear that a new curriculum is needed for Industry 4.0, to prepare a new generation of engineers who can integrate multi-disciplinary and cross-domain knowledge, and able to focus more on understanding the working of system from a systems perspective than merely being an expert on a deeply topical domain of knowledge. These engineers have to cope with new paradigms and concepts (e.g. modelling, simulation, inter-operability and self-organization) and emergent technologies (e.g. IoT, big data and data analytics). Thus, the challenge is to develop and design new curricular programs that focuses such multi-disciplinary specialization, which apparently is contradictory: on one hand to have understanding over a wide plethora of topics and technologies, which can be provided by Bachelor and Master programs, and on the other hand to have short term learning and training programs on specific topics that provide specialization (Leitao, 2017).

While various authors had suggested what an engineering curriculum in Education 4.0 should contain, e.g. Onar et al (2018); FICCI-EY (2017); Coskun, et al (2016); Lorenz, et al (2015); there is still a lack of good framework for which to review an existing curriculum or to design a new curriculum. Although not written specifically to address the challenge of Industry 4.0, Kemp (2016) had provided an excellent review of how engineering education can change to adopt to the challenges in a VUCA (volatile, uncertain, complex, ambiguous) world with a vision for engineering education with 8 key aspects: (1) rigour of engineering knowledge, (2) critical thinking and unstructured problem solving, (3) interdisciplinary and system thinking, (4) imagination, creativity, initiative, (5) communication and collaboration, (6) global mind-set: diversity and mobility, (7) ambitious learning culture: student engagement and professional learning community, and (8) employability and lifelong learning. On the other hand, the CDIO Framework had been widely used since its introduction in 2001. The question we asked is: Can the CDIO Framework be used to aid curriculum review and design under Industry 4.0?

COMPARING CDIO FRAMEWORK WITH INDUSTRY 4.0

The previous sections noted that currently there is a lack of framework addressing educational needs to meet the requirements of Industry 4.0. As noted by Kiel (2017), the lack of research in this area can be attributed to the technical core of Industry 4.0; and hence most works are currently focused on technical challenges and enablers. As collaborators in CDIO, we are interested in finding out if the CDIO Framework that we had adopted for almost 10 years can still serve its purpose of guiding us in the redesign of our engineering curriculum.

We first look at the CDIO Syllabus. The initial syllabus was written in 2001 (Crawley, 2001) with a recent update in 2011, in part to add missing skills and in part to clarify nomenclature to make the Syllabus more explicit and consistent with national standards (Crawley, et al, 2011). We noted that new knowledge required by Industry 4.0 can be effectively covered in Part 1 Disciplinary Knowledge and Reasoning of the CDIO Syllabus v2.0, which is meant to be a placeholder for more detailed description of disciplinary fundamentals necessary for any particular field of engineering. Topics on IoT, CPS, Cloud Computing, Data Analytics, etc can all be covered in Part 1. As Crawley (2001) aptly reminded: “The placement of this item at the beginning of the Syllabus is a reminder that the development of a deep working knowledge of technical fundamentals is, and should, be the primary objective of undergraduate engineering education.”

Unlike Part 1, the remainder of the Syllabus (i.e. Parts 2, 3 and 4) is still common to all engineering professions. Engineers of all types use approximately the same set of personal and interpersonal skills, and follow approximately the same generalized processes. This is a neat arrangement as it allows educational institutions adopting the CDIO Framework to customize the programs to include new knowledge brought about by Industry 4.0 into the CDIO Syllabus without altering the overall general format of the document. As such, we conclude the present CDIO Syllabus has sufficiently captured all the skills needed for Industry 4.0.

Next, we noted that Parts 2, 3 and 4 of the CDIO Syllabus is presented as itemized entries. Within each part, the skills and attributes are further organized into sub-categories down to X.X.X.X level. The number of entries had grown somewhat from version 1.0 to version 2.0. We face some challenges when carrying out validation exercise of the required skill sets with key industry stakeholders. Significant amount of time needs to be invested to ‘educate’ our industry counterparts firstly on the CDIO Syllabus in general, and secondly on the knowledge underpinning each skill. The inter-relatedness of different skills and attitudes also posed problems for them. We also noted that different industry will likely adopt Industry 4.0 in varying degrees (IndustriALL, 2017). Leading the field is industrial engineering and process automation, which see widespread implementation of various Industry 4.0 solutions on the factory floor. The chemical processing industries, on the other hand, already employed extensive process control and management system in its daily operations, and may see more Industry 4.0 applications in streamlining operations across its entire value chain. The skills and attributes needed of process technicians in the chemical processing industry may not have changed much, compared to one involved in process automation at the shop floor. It is therefore paramount that program owners seek validation with industry stakeholders on the revised educational goals in any redesigned curriculum. We find that the Skills Profile approach mentioned in earlier section (see Figure 2) is a more useful and manageable approach for the validation process, and would like to suggest that a review be undertaken by suitable CDIO Collaborators. Program designers should cluster key competencies and proficiency level based on a person’s job roles in a given job function. The same approach is used by other organizations such as OECD in their competency framework (OECD, 2014).

We next turn our attention to the CDIO Standards. Using the information from our review of Industry 4.0 and its implications on engineering education covered previously, we set off studying the CDIO standards one by one, carefully reviewing each standard's "Description" and "Rationale", and view them through the lens of Industry 4.0 to ascertain the relevancy of each standard. Where deem appropriate, each "Description" and "Rationale" is reinterpreted with specific reference to key topics in Industry 4.0. The outcomes are shown in Table 1 below. Each CDIO Standard and its brief explanatory note are shown in grey boxes, and the relevance of that standard to Industry 4.0 is presented below the grey boxes, with brief explanations highlighting how the standard can embrace elements of Industry 4.0.

Table 1. Evaluation of CDIO Standards vis-à-vis Industry 4.0

CDIO Standard 1 – The Context	*Adoption of the principle that product, process, and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education*
Relevance to Industry 4.0: This clearly remains relevant in the context of Industry 4.0, but with the new emphasis on the importance of working in multi-disciplinary teams; as the nature of product, process or system will be different, and so is the lifecycle development and deployment, which is likely to be shorter. An example is in the field of biomedical devices.	
CDIO Standard 2 – Learning Outcomes	*Specific, detailed learning outcomes for personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge, consistent with program goals and validated by program stakeholders*
Relevance to Industry 4.0: As noted in the review of relevance of CDIO Syllabus, the learning outcomes covered in the CDIO Syllabus remain relevant, but validation with relevant stakeholders is of utmost importance, and suggested (see main text) a review of the process using a Skills Profile approach instead of rating each skill one by one.	
CDIO Standard 3 – Integrated Curriculum	*A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills*
Relevance to Industry 4.0: Under this Standard, new knowledge of topics in Industry 4.0 such as Internet of Things (IoT) and data analytics should be covered in suitable module(s), the depth of which depends on the needs of each engineering discipline and year of study. For example, specific information on performance of critical equipment (e.g. catalytic reactors) can be a cursory introduction to IoT for Year 2 chemical engineering, while detailed data analytics is a needed competency in a course on cyber security or consumer behaviourism. Likewise, skills such as virtual collaboration should be integrated into suitable module(s) to develop the required competence over the duration of study.	
CDIO Standard 4 – Introduction to Engineering	*An introductory course that provides the framework for engineering practice in product, process, and system building, and introduces essential personal and interpersonal skills*
Relevance to Industry 4.0: Following up on the point made in Standard 3, all engineering programs should expose students to an introduction of Industry 4.0 and the role it plays in the industry. This could be a modification of existing cornerstone (basic-level) project exercise with the added dimension of Industry 4.0, such as exposure to big data and usefulness of data analytics for example, along with personal and interpersonal skills such as digital literacy, time and resource management.	

Table 1. (Cont'd)

CDIO Standard 5 – Design-Implement Experiences	*A curriculum that includes two or more design-implement experiences, including one at a basic level and one at an advanced level*
Relevance to Industry 4.0: It had to be acknowledge that existing curriculum for almost all engineering education is already very congested. Hence, we do not advocate adding another project to students' capstone (advanced-level) experience. Instead, program owners should carefully review offering of existing projects that involve applications of ideas from Industry 4.0. In this regard, program owners should work collaboratively with the industry it is serving to obtain more industry-related projects for students. Multi-disciplinary projects should be encouraged to the extent possible. At this level, students should be able to demonstrate competence in various CDIO skills, including new skill sets required in Industry 4.0.	
CDIO Standard 6 – Engineering Workspaces	*Engineering workspaces and laboratories that support and encourage hands-on learning of product, process, and system building, disciplinary knowledge, and social learning*
Relevance to Industry 4.0: Consistent with the focus on Industry 4.0 in Standard 5, the notion of Engineering Workspaces should expand beyond the school campus. With Industry 4.0 this should include the shop floor, factory compounds, and processing plants where students complete their internships or industrial attachments. In addition, engineering workspaces should also embrace virtual spaces (virtual learning environments, or VLEs) as well, especially in areas of Augmented Reality and Virtual Reality (AR/VR) where students learn via simulation. Such workplaces, especially virtual ones, can strengthen the 'hands-on' learning with 'minds-on' learning as well, for example, with the AR/VR environment students can try various combinations of possible product, process or system that would be too cost-prohibitive to do with physical items.	
CDIO Standard 7 – Integrated Learning Experiences	*Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills*
Relevance to Industry 4.0: As is the case for Standard 6, collaborating in an online environment such as the cloud, can help foster development of personal and interpersonal skills, and complement the effort in the classroom where face-to-face interactions are taking place. The AR/VR environment can provide a more authentic yet safe experiential learning environment that can better facilitate the acquiring of new skills such as troubleshooting a process the runs the risk of turning hazardous (see also Standard 8 below). An affordance of Industry 4.0 is that it enables the simulation of work environment that goes on 24/7 that suits the work cycle of adult learners.	
CDIO Standard 8 – Active Learning	*Teaching and learning based on active experiential learning methods*
Relevance to Industry 4.0: Cloud, IoT, immersive environment in AR/VR etc all bring about opportunities to engage in active, experiential learning in a new way; especially in terms of online collaboration among peers, or in carrying out (simulated) real world tasks such as emergency response to a chemical accident, that otherwise will be too expensive or dangerous to carry out in campus setting. This also means that higher order thinking skills (exploring different scenarios or outcomes) can be better inculcated. The current active learning methods such as think-pair-share, one-minute paper, etc are still very relevant; but they be made more effective by creative use of technology, notably via the EdTech tools.	

Table 1. (Cont'd)

CDIO Standard 9 – Enhancement of Faculty Competence, and	*Actions that enhance faculty competence in personal and interpersonal skills, and product, process, and system building skills*
CDIO Standard 10 – Enhancement of Faculty Teaching Competence	*Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning*
Relevance to Industry 4.0: The changes in ways that learning can take place under Industry 4.0 as discussed in earlier sections require that lecturers adapt their teaching to suit the new learning environment. Lecturers need to learn new ways to engage students via the cloud, EdTech tools, use of AR/VR, etc. They need to integrate new skills identified in Industry 4.0 into the modules they are teaching. Lecturers also need training on how to use data analytics to obtain real-time analysis of students learning experience, and devise corrective actions as necessary. Skills in digital coaching and joint problem-solving in virtual world will be needed. Lastly, lecturers need to update their knowledge in how Industry 4.0 is affecting the industry their program is serving. This requires careful planning for staff industrial attachment especially in times of manpower crunch.	
CDIO Standard 11 – Learning Assessment	*Assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge*
Relevance to Industry 4.0: Just as Industry 4.0 affect the ways students learn, it will also affect the ways assessments are carried out. For example, the affordances of data analytics will bring about changes in the way students are assessed. More focus can be directed towards formative assessment when data are available in real-time to address specific learning challenges (such as misconceptions, wrong assumptions) encountered in class. Higher-order or more challenging assessments can be carried out based on real-world "What-If" scenarios (see Standard 8) based on simulated emergency situations in AR/VR.	
CDIO Standard 12 – Program Evaluation	*A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement*
Relevance to Industry 4.0: This standard will always be relevant as it relates to continual improvement. As noted in Standard 1, and in the main text, adoption of Industry 4.0 will differ from industry to industry, and so are the skill sets. Furthermore, it can be expected that advancement in technology will further influence the development of new skills. Hence it is of paramount importance that the program be evaluated regularly, for example, within 3 years instead of the more commonly accepted period of 5 years.	

In summary, our comparison of the CDIO Syllabus and Standards showed that the CDIO Framework is still relevant to Industry 4.0. However, the required curriculum and the way learning that will take place in the future will be quite different. More specifically, the curriculum need to broader to offer more opportunities for multi-disciplinary project work, and cross-linking subjects such as data analytics or CPS via free electives. These subjects may even be delivered by industry professionals, who possess the latest technical know-how is this fast-changing area. Also, more learning will increasingly be realized at the workplace itself, such as via internships lasting 6 months or longer. Achieving these will require program owners to actively engage the relevant industry partners.

To this end, we opined that existing standards may fall short in 2 areas – one is the need for educational institutions to more actively engage key stakeholders, notably, the potential employers; and another to provide guidance for educational institutions to manage students' learning at the workplace. We therefore propose to introduce 2 new standards as presented in the next section.

RECOMMENDATIONS

The first additional Standard we propose, tentative labelled Standard 13, is that of Industry Engagement, defined as "Actions that education institution undertake to actively engage industry partners to improve its curriculum". The aim of any curriculum revamp is to prepare industry-ready graduates. Some of the learning outcomes stipulated in program aims or articulated in the institution's graduate attributes can only be realistically achieved in real-world work settings. Having supportive industry partners can help to ensure that such learning experiences be delivered to students. Learning in real-world context is meaningful and engaging for students, it not only helps make the connections between what is learnt in campus and what is being practiced in the industry, but can also help improve their understanding of real-world expectations and shape their mind sets, making them life-ready, work-ready and world-ready. The CDIO Standard had been noted to be useful for engagement of industry stakeholders (Male, King & Hargreaves, 2016). The importance of industry engagement is numerous, and it can address the requirements spelt out in most, if not all, of the existing 12 CDIO Standards.

Industry partners play a crucial role in the training of students to be the professionals in their field, for example, by providing them opportunities to experience real-world work environment via industrial attachment or internship (Standards 1, 7). Students can also work on real-world projects while on industry attachment or internship, or in campus working on industry-sponsored projects (Standards 5, 6). Industry partners can serve as judges evaluating the work done by students (Standard 11). Even routine, office-type work is authentic and experiential for students (Standard 8). Industry partners can also complement students' academic studies by taking up teaching role as adjunct professor, as speakers for course seminars, or as members of a program's advisory panel. They can also partner with academic staff to jointly develop curriculum that is directly relevant, up-to-date and useful to the industry. In addition, industry partners can also support the educational institution's continuous professional development program by offering staff placement opportunities for teaching faculty to upgrade his/her technical know-how (Standards 9, 10). Of course, the issue of industry engagement is not new, and it may be argued that industry engagement is already implied in Standard 1 (CDIO as Context) and Standard 12 (Industry partners and stakeholders).

However, we believe that the advent of Industry 4.0 has brought to the fore its importance. We believe that having a new standard specifically aimed at Industry Engagement has its merit, to make explicit the necessity of actively seeking industry feedback not just in designing of our curriculum, but also in delivering them for example through co-teaching and co-supervision of projects.

The second additional Standard we propose, is tentatively labelled Standard 14 Workplace Learning. Traditionally the concept of "learning" has been related to formal education, i.e. in classrooms in educational institutions. Keen interest in workplace learning are now on the rise, driven by unprecedented changes brought about by recent technological development, most recently under the banner of Industry 4.0. The classic work that highlight differences between learning in educational institutions and learning elsewhere (at work, for example) was provided by Resnick (1987). Recent research on the outcomes of education particularly at the tertiary level, has shown that there is gap between the knowledge and skills needed at work and those produced through formal education (Tynjala, 2008). Billet (2014) had long argued that there is no separation between participation in work and learning, as individuals engage in work activities and interactions they learn through that engagement. Workplace learning can enhance in-campus learning by providing students with opportunities to apply classroom knowledge in real-world setting, and in some cases, to deepen that technical capability. It can also add value to the development of desired graduate attributes such as professional and ethical responsibility, appreciation of social, cultural and environmental context of engineering practice, etc – the sorts of abilities that cannot be acquired by sitting in lecture halls.

There had been various definitions of workplace learning, with terms such as work-based learning, work-integrated learning, and work-related learning are all being used in various literatures. Griffith & Guile (2004) for example, suggested a topology of 5 models of work experiences. In the present context, we define workplace learning as "A curriculum that includes students working in a real-world work environment with the aims of strengthening in-campus learning and developing their professional identity."

While there remained many challenges in implementing workplace learning, such as maintaining consistent desired learning outcomes among students attached to different companies, Radcliffe (2002) argued that technological advances had made possible the pedagogical convergence between work-based learning and campus-based learning. Against these developments, we felt that existing CDIO Standards supplemented with a separate standard on workplace learning is warranted to guide faculty in designing a more authentic learning experience for students.

Details of the proposed 2 new standards are shown in Appendix 1, using the "traditional" CDIO template providing a brief description and rationale for the standard, and the corresponding set of rubrics. The definition of Workplace Learning may warrant further clarifications to arrive at a common understanding of the terminology within the CDIO community as well as for potential collaborators. Likewise the suggested rubrics are by no means definitive. We would encourage debate within the CDIO community to refine them using the approach suggested by Bennedsen, et al (2017) when they proposed an updated rubric for the CDIO self-evaluation.

CONCLUSION & FUTURE WORK

This paper provides a brief introduction to Industry 4.0, and shares the outcome of a study of into the relevance of CDIO Framework to Industry 4.0. It concludes that the CDIO Framework – both the Syllabus and Standards – still remains relevant as reference document to guide the redesign of engineering education. For the CDIO Syllabus, it is suggested that the skill sets be validated with key stakeholders using a "Skill Profile" approach rather than itemized listing when the framework was first formulated. For the CDIO Standards, it is suggested that their interpretation be enlarged to embrace specific features brought about by Industry 4.0, notably the real-world learning via industry projects, virtual learning environment and collaboration. Lastly, it is also suggested that 2 new Standards – namely Industry Engagement and Workplace Learning – be introduced.

It is believed that the ideas presented and recommendations given will prove valuable to program owners on how to use the CDIO Framework to revise their curriculum to better prepare graduates for the world of Industry 4.0. In the same spirit as expressed by Malmqvist, Edstrom & Hugo (2017), the authors too, suggest that the proposal in this paper be treated as first drafts, to be further studied by the CDIO community for their merits and acceptance.

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Appendix 1 Recommendations for 2 New CDIO Standards

Standard 13 – Industry Engagement

Actions that education institution undertake to actively engage industry partners to improve its curriculum.

Description:

Industry partners play a crucial role is the training of students to be the professionals in their field, for example, by providing them opportunities to experience real-world work environment via industrial attachment or internship (Standard 1, Standard 7). Students can also work on real-world projects while on industry attachment or internship, or in campus working on industry-sponsored projects (Standard 5). Industry partners can also complement students' academic studies by taking up teaching role as adjunct professor, as speakers for course seminars, or as members of a program's advisory panel. Industry partners can also support the educational institution's continuous professional development program by offering staff placement opportunities for teaching faculty to upgrade his/her technical know-how.

Rationale:

The aim of any curriculum revamp is to prepare industry-ready graduates. Some of the learning outcomes stipulated in program aims or articulated in the institution's graduate attributes can be realistically achieved in real-world work settings. Having supportive industry partners can help to ensure that such learning experiences be delivered to students. Learning in real-world context is meaningful and engaging for students, it not only helps make the connections between what is learnt in campus and what is being practiced in the industry, but can also help improve their understanding of real-world expectations and shape their mind sets, making them life-ready, work-ready and world-ready.

Rubric:

Scale	Criteria
5	Industry engagement is institutionalized, and forms part of the program's continual improvement process.
4	Part of the program is developed with industry input, and delivered jointly or severally by industry partners, and reviewed for relevance.
3	An industry review panel has been set up and periodic meetings conducted.
2	Industry partners are occasionally engaged in delivering guest lectures on selected topics in the curriculum, or as adjunct lecturers.
1	The need for industry engagement is recognized and benchmarking study has been planned or in progress.
0	There are no plans or practices to engage industry partners in the program's teaching.

Appendix 1 (cont'd)

Standard 14 – Workplace Learning

A curriculum that includes students working in a real-world work environment with the aims of strengthening in-campus learning and developing their professional identity.

Description:

The workplace can be an important place for learning and development, and in which knowledge can be created and skills acquired. In the workplace, the acquisition of knowledge or skills can occur via both formal or informal means. Workplace learning occurs mostly through work-related interactions and is generally described as contributing to the learning of both the individual employee and the organisation as a whole. Learning at the workplace can take place via self-directed learning, networking, coaching and mentoring.

Rationale:

There are limitations on what students can learn within the campus setting. Students may also be "sensitized" to the school environment and not well prepared for the real-world, for example, in exercising of interpersonal skills or decision making on ambiguous issues often with conflicting perspectives. Workplace learning can also help to instill in students greater sense of professional identity and sense of responsibility.

Rubric:

Scale	Criteria
5	Industry attachment or internship programs are structured with clear learning outcomes and jointly formulated with industry partners, and continually reviewed to improve the student learning experience.
4	Longer-term student attachment or internship in place, but without detailed structure for its execution to attain the desired learning outcomes.
3	Students attended short-term (2 to 6 weeks) of industry familiarization program.
2	There are some ad hoc study trips conducted for students to get exposure to the relevant industry.
1	The need for workplace learning is recognized and benchmarking study has been planned or in progress.
0	There are no plans or practices to provide students with opportunities for learning in the relevant industry for which they are trained.