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Reimagining Engineering Education: Does Industry 4.0 need Education 4.0?

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Abstract

Industry 4.0 is a commonly used term to refer to the fourth industrial revolution that is currently underway. The hallmark of this transformation is the effect of digital technologies such as Internet of Things, Robotics, Cloud Computing, Additive Manufacturing, Artificial Intelligence and others on the way we make things and the way we do business. Unlike in earlier transformations, technological change is happening at an exponential rate; as a result, artifacts, knowledge, and expertise are becoming obsolete at a very fast rate.

In this climate of exponential technological change as educators we need to ask hard questions, such as: Is the current system of engineering education appropriate for the current time? Are we behind our times by many decades? What should the new model of engineering education be? Should we have an Education 4.0 movement to go hand-in-hand with Industry 4.0? What would Education 4.0 look like? Naturally all of these are difficult questions to answer. We explore these questions critically and in the context of engineering education and discuss pockets of efforts that are underway in different corners of the education landscape to address these critical questions.

Introduction

Industry 4.0 is the universally used term for the fourth industrial revolution. Researchers have identified major technological innovations that brought about huge changes in society, industry, and the economy as industrial revolutions. The first industrial revolution (Industry 1.0) is associated with the development of the steam engine in the 1780s that led to a remarkable change in people's mobility and the availability of a source of energy and power that could be harnessed for the benefit of society. Increased mobility of people led to mass-migration from rural areas to urban centers. And the agriculture-based economy started to transform to an industrial economy. Henry Ford's assembly line, implemented in the early 1900s is associated with the second industrial revolution (Industry 2.0), an era of mass production. The revolutionary idea of an assembly line resulted in repeatability, efficiency, affordability, and high-volume manufacturing. Millions of new jobs were created, economic upward mobility of the middle class accelerated leading to enormous growth of wealth. Computerization and Automation which started impacting industry in the 1970s is associated with the third industrial revolution (Industry 3.0). With automation and computerization of operations many manual functions got replaced by machines. From assembly to accounting applications of software and hardware to automate routine tasks resulted in significant improvement in productivity, efficiency, and economic growth. Large manufacturing corporations, once employing thousands or workers, shrunk in size while their wealth and profits grew. The skills needed in the workforce shifted from manual skills to intellectual skills and expertise. The industrial economy started to transform into information economy. The advent of the fourth industrial revolution (Industry 4.0) started in the early 2000s when the machines of automation, the robots and computers started getting connected through wireless technology. This era is marked by growth of technology at a breakneck speed. We are now in the era of "smart factories" that are getting connected by cyber-physical systems. Systems such as IOTs (Internet of things) are connecting machines with humans and other machines. Enormous amount of data (Big Data) are being collected and processed in the cloud (Cloud computing). Model based predictive maintenance and failure prevention are becoming routine. All this is leading to further reduction of traditional workforce and repurposing of jobs. Through the harnessing of all these technologies the scenario of a single worker managing a large automated assembly floor is becoming a reality.

The transition from industry 1.0 to 2.0 took almost a century and a half, the time between the industry 2.0 and 3.0 was a few decades and the transition from industry 3.0 to 4.0 was even shorter. This shrinking of periods between transformations was driven by the pace of technological change. At the moment, technological changes are happening at an exponential rate and Industry 4.0 is destined to change a lot of things in ways that may be quite unfathomable.

All these industrial revolutions did not just influence industrial productivity, the labor market and the educational system were altered permanently. As a result of these changes some professions and jobs have disappeared. Currently, due to the development of digitalization and robotics, we are facing a similar era of change. "*We are currently preparing students for jobs that don't yet exist, using technologies that haven't been invented, in order to solve problems, we don't even know are problems yet.*" Most of us have come across this famous insight from former Secretary of Education, Richard Riley. Here are some key pointers from a recent publication (Walsh).

- 65% of children entering elementary school this year will work in a job that hasn't been invented yet

- 49% of current jobs have the potential for machine replacement, with 60% having at least 1/3 of their activities automated

- 80% of the skills trained for in the last 50 years can now be outperformed by machines

- At a global level, technically automatable activities touch the equivalent of 1.1 billion employees and $15.8 trillion in wages

The rapidly changing landscape of the workplace and associated uncertainty has raised a lot of questions about the future of our education system. The impact of different industrial revolutions on education, just like all other parts of society has been profound. Education 1.0 was no education at all. At that time children worked in manual jobs and child labor was the order of the day. Education was not necessary to earn a living, it was merely a luxury for the elites and the rich. Education 2.0 originated from the need to read and write and was developed in the model of Industry 2.0, with emphasis on repeatability, uniformity, efficiency, and mass production. Industry needed lots of people to do same type of tasks and the education paradigm evolved to meet that need. Engineering education, which modeled the industrial set-up most closely followed a highly linear path with curriculum being divided into a set of courses with a distinct prerequisite structure where students would have to pass one class to move onto the next. This arrangement, mirrored the assembly line and turned out to be the most efficient arrangement. Education 3.0 did not constitute much of a paradigm shift. The advent of automation meant that the education system now could do the same thing they were doing but faster and more efficiently. College professors who wrote on chalk boards switched their lectures over to electronic presentations, engineering drawing skills were replaced by CAD, and calculators and computers replaced slide rules. But there was hardly any change in the paradigm. Classrooms have remained teacher centric, learning in classrooms is overwhelmingly a passive exercise, and standardization of curriculum and testing continues to remain the order of the day. Driven by the needs of Industry 4.0 and associated speed of technological change, conversation has started in many concerned circles about the future of work and future of education. What should Education 4.0 look like? Here are some relevant quotes from recent publications.

"The emerging technologies have huge effect on the education of people. Only qualified and highly educated employees will be able to control these technologies."
(Benešová & Tupa)

"*The argument is simple: the change is here, there's no avoiding it, so it's time to adapt. Institutions must change to keep up — and I don't mean they need reform; there's no use in improving a broken model. We are on the brink of a fourth industrial revolution, and we need a full-scale transformation, an education revolution to keep up to the world of 4.0." (Walsh)*

"Education 4.0 is catering to the need of the society in 'innovative era'. It is in accordance to the changing behavior with the special characteristics of parallelism, connectivism (Goldie), and visualization. This learning management must help to develop the learner's ability to apply the new technology, which will help the learner to develop according to the changes in society. Learning management of this era is a new learning system, allowing the learner to grow with knowledge and skills for the whole life, not just to know how to read and write (Sinlarat). To be able to live in a society and to be equipped with the best of his/her ability. Therefore, Education 4.0 will be more than just an education." (Puncreobutr)

"*Our students will have to succeed in a working environment which is increasingly globalized, automatized, virtualized, networked and flexible. Many jobs, such as Social Media Manager, Blogger, App Designer, App Developer, Big Data Analyst seem quite conventional to us today. However, they did not exist 10 years ago and these are not purely "digital" jobs either: they require a sound knowledge in the field of application as well." (* Wallner & Wagner *)*

"Education 4.0 is a response to the needs of IR4.0 where human and technology are aligned to enable new possibilities. Fisk explains that the new vision of learning promotes learners to learn not only skills and knowledge that are needed but also to identify the source to learn these skills and knowledge. Learning is built around them as to where and how to learn and tracking of their performance is done through data-based customization. Peers become very significant in their learning. They learn together and from each other, while the teachers assume the role of facilitators in their learning." (Hussain).

In the next few sections we explore the concept of Education 4.0 further with primary focus on engineering education in 4-year degree programs.

What is Education 4.0?

There is really no formal definition of Education 4.0. Thought leaders have identified characteristics of Education 4.0 and there has been a lot of discussion on how it ought to be different from the current model of education. In the current system, engineering programs receive raw materials, I.e. students graduating from high schools aspiring to get a college degree. In college, particularly in engineering, students primarily follow a prescribed curriculum in a format that is largely traditional, classroom-based instruction. The curriculum is prescribed by external entities such as universities, programs, accreditation agencies such as ABET, and professors; this means the students are required to learn materials that "others" prescribe. It has to be done as per a set schedule, i.e. in prescribed time blocks, semesters or quarters, and following a prescribed prerequisite structure. After finishing four years of curriculum students graduate and join the workforce. Current education paradigm uses the "Empty Container Paradigm." It is assumed students will start a given course knowing nothing about the topic and while they are enrolled in it knowledge will be poured in their head as is done in an empty container. In this current model, learning occurs individually, there is a lot of emphasis on prerequisite structure and requirement for basic knowledge, and assessment is based on grades in tests rather than acquiring of a skill. One other very important practical difficulty occurs due to this linear learning process. The time gap between when a concept is learned and when the learner gets to use it is so long that the learner forgets a lot of the material and therefore is unable to connect the learned material with its application.

Review of recent publications that have discussed the need for a new paradigm in education, and especially STEM education, provides some guidelines of what needs to change. In 2015, the World Economic Forum published a report on the pressing issue of 21st-century skills gap and ways to address it through technology (*New Vision for Education: Unlocking the Potential of Technology*). In this report, the authors defined a set of 16 crucial proficiencies needed in the 21st century. They are divided into three categories, foundational literacies, competencies, and character qualities. In 2018 World Economic Forum also published a *Future of Jobs Report* that lists the top 10 skills needed in the future workforce.

American Society of Engineering Education (ASEE) with support from the National Science Foundation (NSF) has been engaged in a multi-year effort to identify the Knowledge, Skills and Abilities (KSA) of the future Engineering Workforce. This four-part summit is called *Transforming Undergraduate Engineering Education* (TUEE) and the first part that focused on Synthesizing and Integrating Industry Perspectives was held in 2013. Phase 2 and 3 focused on listening to the students, the future workers, and listening to the voices of women, respectively. They were held in 2017. Phase 4 was held in 2018 and was devoted to listen to the voices of the faculty. In the first phase of this effort 36 KSA areas were identified of which 15 were considered high priority. All these competencies and traits from the above three publications are summarized in Table I.

Table I: Competencies needed in the future workforce

Future of Jobs Report	New Vision for Education Report	ASEE-TUEE

Complex problem Solving	Foundational Literacies	Literacy	Good Communication skills
Critical thinking		Numeracy	Physical and Engineering Sciences Fundamentals
Creativity		Scientific Literacy	Ability to Identify formulate and solve engineering problems
People management		Information and Communication Literacy	Systems Integration
Coordinating with others		Financial Literacy	Curiosity and Persistent Desire for Continuous Learning
Emotional intelligence		Cultural and Civic Literacy	Self-drive and motivation
Judgement and decision making	Competencies	Critical Thinking	Cultural awareness in the broad sense (nationality, ethnicity, linguistic, gender, sexual orientation)
Service orientation		Creativity	Economics and Business Acumen
Negotiation		Communication	High ethical standards, integrity, and global, social, intellectual, and technological responsibility
Cognitive flexibility		Collaboration	Critical Thinking
	Character Qualities	Curiosity	Willingness to take calculated risk
		Initiative	Ability to prioritize efficiently
		Persistence/grit	Project management (supervising, planning, scheduling, budgeting, etc.)
		Adaptability	Teamwork skills and ability to function on multidisciplinary teams
		Leadership	Entrepreneurship and intrapreneurship
		Social and Cultural Awareness	

These three lists derived from three sources show how remarkably similar the skills are even though the ASEE list is specific to engineering. A consensus seems to be emerging among many groups regarding the skills needed in the workforce of tomorrow. It is worthwhile to mention that these critical reviews of the needs of today's industry and the associated changes needed in education are nothing new. In early 2000 several similar efforts were undertaken. *Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education* (Duderstadt), was an elaborate report published from the University of Michigan.

This report built on prior studies such as the National Academy of Engineering studies: *The Engineer of 2020* (Parts I and II) (2004, 2005), *Engineering Research and America's Future* (2005), and the National Academies study, *Rising Above the Gathering Storm* (2005). It is quite interesting to note that some of the skills that are being emphasized now were listed in these earlier reports as critical necessities. Duderstadt's recommendations included some large-scale changes involving government, academia and industry partners to re-vamp the engineering education ecosystem of the nation. Needless to say, most of that has not happened. All the evidence just goes to show that the needs assessment is reliable and have strong support among the peer community.

In the European Union (EU) a project was undertaken on this same issue called *The Universities of the Future (UoF)* project that aimed at identifying the educational needs arising from Industry 4.0 in Europe. Funded by the EU, this report identifies the skills required for succeeding in the Industry 4.0 environment. In this report, the authors reviewed all current relevant publications and developed a list of technical and soft-skill competencies needed to be successful and productive in Industry 4.0. The list of soft skills is similar to the other competencies shared above. In Table II we list all the identified technical competencies separated as engineering, business and design competencies.

Table II: Engineering, Business and Design Elements of Industry 4.0

Engineering Competencies	**Business Competencies**	**Design Competencies**
Data Science and advanced (Big Data) analysis	Technology awareness	Understanding the impact of technology
Novel human-machine interfaces	Change management and strategy	Human-robot interaction and user interfaces
Digital-to-physical transfer technologies, such as 3D printing	Novel talent management strategies	Tech-enabled product and service design
Advanced simulation and virtual plant modeling	Organizational structures and knowledge	Tech-enabled ergonomic solutions and user experience
Data communication and networks and system automation	The role of managers as facilitators	
Artificial Intelligence	Tech-enabled processes: Forecasting and planning metrics, scheduling	
Robotics		
Programming skills		
Closed-loop integrated product and process quality control/management systems		
Real-time inventory and logistics optimization systems		

Given that all these skills are necessary, what should the re-invented education system look like so that students of today are successful in the age of Industry 4.0? Peter Fisk identifies the following characteristics of Education 4.0 (Fisk):

Characteristics of Education 4.0 (Fisk)

1. **Diverse time and place:** students will need to learn at different times and different places, e-learning will be a critical part of the system. Concepts of flipped classrooms will have to be implemented more universally when students will learn the theory on their own and do hands-on applied work during in-person sessions.
2. **Personalized learning:** students should be able to learn at their own pace. The tools should be adaptive so that students with advanced capabilities can move faster and complete more difficult tasks while beginners can take time to master rudimentary skills before moving on. Students will need to receive positive reinforcements and encouragements so that they can move forward with confidence.
3. **Free choice: Learning styles of individuals vary, it is imperative that the students should be free to use their own combination of learning tools and methodology.** Students will learn with different devices, different programs and techniques based on their own preference, such as blended learning, flipped classrooms and BYOD (Bring Your Own Device), etc.
4. **Project based:** Learning will need to be project based and replicate the real-world as closely as possible. They should be able to apply their skills in a variety of situations, including skills such as organization, teamwork, time and project management, etc.
5. **Field experience:** experience in the job will be even more important so education plan will need to involve more field experience through a variety of means such as internships, industrial projects, co-ops and mentoring.
6. **Data interpretation:** today's computers can do all the mathematical skills that students have to master. More and more, mastering these skills will become less important and analyzing and interpreting data will gain in importance. Interpreting data to discover trends and infer logic will become the trend of the future.
7. **Exams will change completely:** assessment of learning to apply knowledge and mastery of skills will be tested as learning happens. The current form of the exams where students have to cram and then regurgitate will become obsolete.
8. **Student ownership:** students will become the master of their learning. They will have a stronger voice in the curricula and designing their learning goals. Critical input from students on the content and durability of their courses is a must for an all-embracing study program.
9. **Mentoring will become more important:** teachers and other experts will have to work more as mentors and coaches in the world of learning for the students. These mentors will provide a valuable service in helping the students chart a path through the maze of information that is now available in front of them.

In a paper titled *Academic Education 4.0*, Waller and Wagner developed a list that would guide the formation of a new educational system to prepare our students to be successful in the future (Waller and Wagner):

1. **Individualized:** In order train our students to be successful in the complex world a standardized program is not the right one. Standardization always means simplification, and thus standardized programs cannot deliver what we need. Lectures are not the right mode of delivery of such a program; it will require individualized education.

2. **Student-driven:** The education system needs to enable and support the self-organizing capacity of our students. Students should be defining their own study goals. Autonomy (self-organization), purpose and mastery are the fundamental elements of intrinsic motivation.
3. **Interdisciplinary:** Our future challenges are increasingly interdisciplinary and transdisciplinary. This means that a stable and well-defined range of subjects is becoming obsolete. We need to provide a structural overview in their field of study that will enable them to integrate the knowledge they are constantly acquiring. It will be our job to provide this framework.
4. **Mode of Assessment:** Standardized tests or general exams are useless. Student assessment should be based on their individual reflection of their own learning progress and their contributions to the collective learning process.
5. **Source of Knowledge and Information:** Our students have numerous information sources (books, articles, search engines, blogs, MOOCS etc...). We cannot act as subject matter experts any more. But we will need to play the role of integrator/mentor/coach so all the information can be optimally used.
6. **Setting for Learning:** Learning is a social activity. We have to open our campuses and invite students in to use this space as a place for meetings and encounters, for discussion and collaboration. One-to many lectures is one of the least effective ways to transfer knowledge. Research shows, that traditional lecturing is less effective than active learning. (Freeman et.al.). Ambience and learning space is important for the important learning processes. We need to provide these types of "enabling spaces", which can be arranged according to these social settings we mentioned.

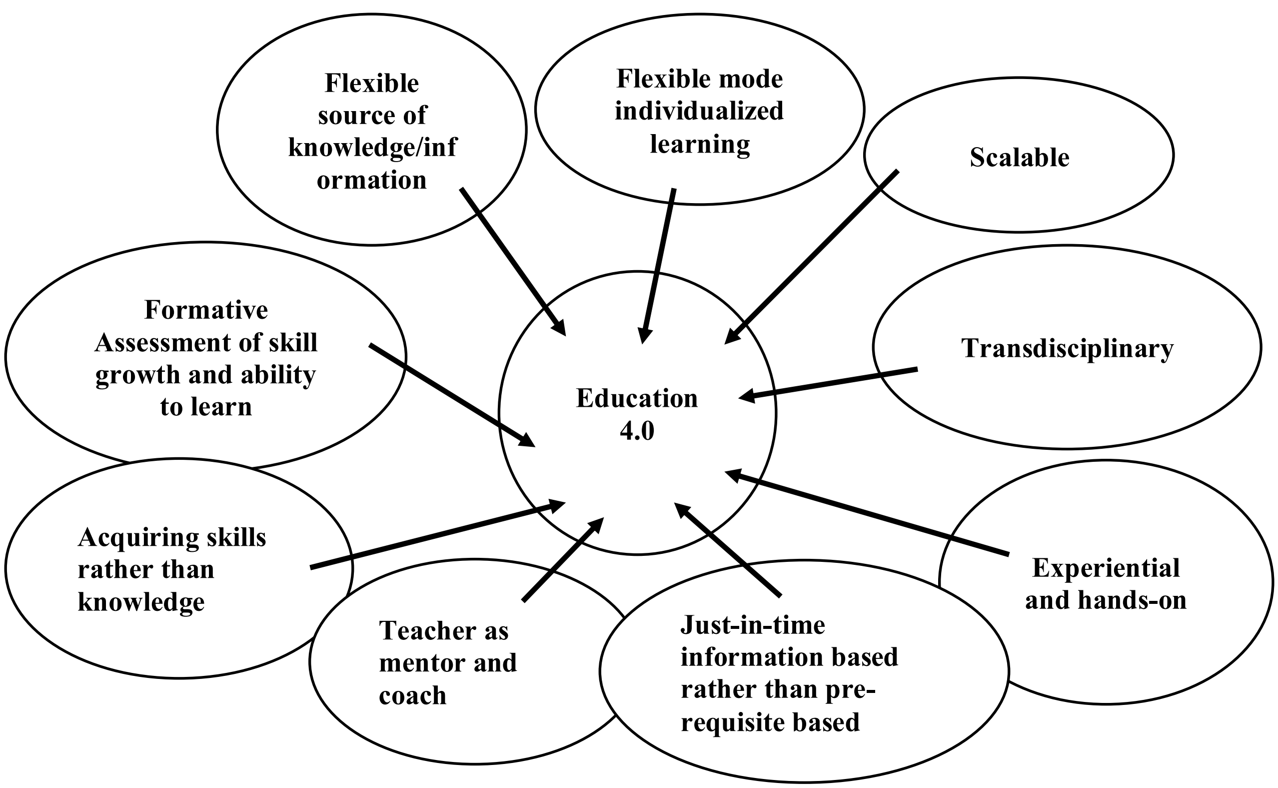

Figure 1: Characteristics of Education 4.0

Figure 1 captures all the characteristics discussed through a visual. In the next section we discuss some of the challenges.

Education Ecosystem and the challenges of implementing changes

Figure 2 shows a schematic for the engineering education ecosystem. There are three distinct zones in the ecosystem, the first zone is pre-college where high school students are getting ready to embark on a college experience, the second zone is the college itself and the third zone is the workplace or the industry that will employ the student. These three zones are intertwined and any effort to change the current status-quo needs to look at this ecosystem holistically. In this section we will discuss some of the challenges that are to be overcome in order to implement changes. Most of the items on these lists were developed through interviews with industry leaders and through literature search.

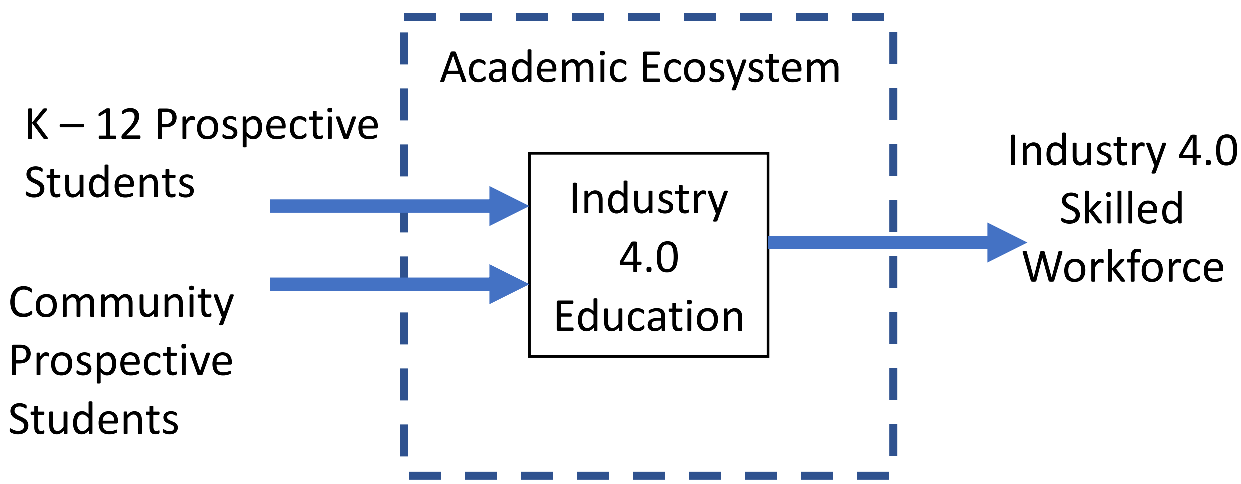

Figure 2: Education eco-system.

Pre-college zone

1. Academia struggles to find enough K-12 prospects to sufficiently feed the I4.0 pipeline.
2. Students unprepared in key areas such as Mathematics and Physics. Particularly Physics education in US high schools is abysmal (Mathewson). Only about 40% of high school students in the US graduates with some course in Physics. Even that percentage is not uniform across all states. Some parts of the country may have over 80% students studying Physics and in other parts it is as low as 10-20%. There is a huge shortage of Physics teachers all across the country and The American Institute of Physics study found that a majority of the schools where physics isn't offered at all are attended primarily by students of "low socioeconomic status," and that black and Latino students are far less likely to take high school physics than their white and Asian peers. Physics is the basis of all engineering and physical sciences disciplines. This is a huge problem that needs a lot of attention.
3. It is difficult to explain the nuances of Industry needs to K-12 prospects and expect them to sign up for a new/unknown education tract. Although this group is also much more adept with many of the technologies used in Industry 4.0 than any prior generation.

4. The pool of K-12 prospects is dwindling due to population demographics and lower interest in traditional education programs.
5. Interest in Industry is being overshadowed by concerns for the environment, the promise of e-business, Apps, etc.
6. Due to concern about college costs there may be a community perspective community prospective that student needs upskilling or retraining; but at the same time many are unlikely to want and/or afford a 2- or 4-year traditional degree.
7. There is misconception about the depth and breadth of on-demand learning (i.e. Ted-X, YouTube Videos, LinkedIn learning, etc.)

The college-zone

1. There isn't enough current faculty with I4.0 skills to fill the curriculum requirements.
2. Existing curricula is already congested, filling accreditation requirements. It is a zero-sum game, adding new material requires deletion of some existing content.
3. Traditional credit-hour, semester-based course delivery may not facilitate rapid inclusion of I4.0-specific content.
4. Rapidly changing technology has become the norm, but the academy is not agile.
5. The cost of equipment and facilities is prohibitive, especially rapidly changing tech that is virtually "disposable".
6. The faculty promotion and tenure system is not designed to promote curricula experimentation.
7. The difficulty of scaling-up from a successful effort with a small group of students to a larger student body.
8. The university system favors and rewards research, and is designed to train students for graduate schools and research, which overshadows the work to develop quantities of I4.0 skilled workers who will work in industry after an undergraduate degree.
9. University research is often given priority over workforce preparation.
10. Community colleges have to balance college-prep track against skilled-trades tracks, while the need for I4.0 workers covers both.
11. There is no direct financial transaction or cash flow affected by undergrad outcomes.

Workplace zone

1. Academia is reluctant to make dramatic changes to the education process when it is unclear that industry will have positions for the graduates.
2. Industry will claim to need I4.0 skilled workers, but will only hire graduates with traditional, commonly recognized degrees or even international personnel who are already trained.
3. Academia relies on industry and advisory boards to gage the technical needs of their industry partners. Often, the industry liaison role is handled by "Learning and Development" or "Human Resources" departments, with limited knowledge of the actual needs in I4.0 technical staffing.
4. There is no direct financial transaction with industry. Academia is instead drawn toward government research dollars.

It is interesting to see how these statements line up with what other major studies have found. The ASEE TUEE report quotes the participants as saying:

- "Assessment poses a big challenge. ABET may need to be involved."
- "Faculty will feel at a loss grading reflection, and a lack of clear expectations will cause students to fret."
- "Moreover, engineering faculty cannot control general education requirements."
- "Freshmen, it was noted, are ill-prepared for open-ended projects."
- "Co-curricular activities detract from time devoted to academic activities—and how do you grade them?"
- "When you ask me to do more, I have to do less somewhere else . . . my class is too large . . . Why are we doing this; it's not our responsibility . . . there's no budget for it."
- "The reason our colleagues don't do active learning is that they're scared of being in a student-centered environment where they might be asked questions they don't know the answer to."

In the Engineering for a Changing World report Professor Duderstadt writes, "*However, the resistance to such transformations will be considerable. Industry will continue to seek low–cost engineering talent. Educators will defend the status quo, as they tend to do in most fields. And the great diversity of engineering disciplines and roles will continue to generate a cacophony of conflicting objectives that prevents change. Yet while the views of industry leaders, educators, and professional groups should be considered, it is essential to recognize that American engineering must be transformed if it is to be responsive to the changing needs of a nation, a world, and, of course, prospective and practicing engineers.* "

In 2018 MIT published a report entitled *The Global State of the Art in Engineering Education* (Graham). This study took a thorough look at the state of the art of undergraduate engineering education globally. It was done to inform an MIT initiative, *New Engineering Education Transformation* (NEET), to develop and deliver a world-class program of undergraduate engineering education. The study used a thorough interview process of thought leaders in Engineering Education to identify the cutting edge of global engineering education and the state of the art that is likely to develop in the future. From the MIT report the major challenges listed are:

- the alignment between governments and universities in their priorities and vision for engineering education;
- the challenge of delivering high-quality, student-centered education to large and diverse student cohorts;
- the siloed nature of many engineering schools and universities that inhibits collaboration and cross-disciplinary learning;
- faculty appointment, promotion and tenure systems that reinforce an academic culture that does not appropriately prioritize and reward teaching excellence.

Now that we have seen a summary of what Education 4.0 ought to look like and what some of the challenges for implementing transformation are, we will consider some programs where changes have been happening.

Recent efforts in Engineering Education reform and case studies

While the paradigm of engineering education has remained broadly the same for many years, changes have been happening in many aspects of programs. These changes include mandatory co-ops or internships, industry-sponsored and industry-directed projects, mentorships, undergraduate research, on-line learning, flipped classrooms, and many others. Individual programs and changes are too many to list here individually. The scalability of these types of changes has always been challenging in the current educational paradigm.

The 2018 MIT report mentioned in the previous section separates programs into two categories, ones that are considered leaders at the current time and a second category of "emerging leaders." In a second part of the report case studies of four "emerging leaders" in engineering education are discussed: Singapore University of Technology and Design (Singapore), University College London (UK), Charles Sturt University (Australia) and TU Delft (Netherlands), and discussed them in great details. Here we will summarize some of the findings.

In preparation of this report one of the questions asked was to identify features or characteristics of universities that make current leaders unique and those that make some programs "emerging leaders." The list of current leaders included many familiar names such as MIT, Stanford, Olin College, etc. The summary of results indicate that current leaders stood out because of their emphasis on user-centered design, technology-driven entrepreneurship, active project-based learning and a focus on rigor in the engineering 'fundamentals'. The emerging leaders were programs that were either developed from a blank slate or through large-scale systemic educational reform that were driven by regional or local needs. The unique features of the 'emerging leaders' included work-based learning, multidisciplinary programs and a dual emphasis on engineering design and student self-reflection. About all the emerging leaders the report states:

"All the leaders showed a forward-thinking vision and strong personal commitment towards a new paradigm of engineering education. They are inclusive, and open to new ideas and feedback to help achieve excellence. Faculty demonstrate a spirit of collegiality and common purpose. This is an important aspect to allow new ideas, practice and experimentation to emerge. All these places show a high level of student engagements. Even though they may have been skeptical at the beginning, students are bought into the new paradigm and participate with commitment and enthusiasm. All of these institutions have developed specialized in-house tools to help with implementing their vision. These range for assessment tools for use in non-traditional learning to online content for students to use in fully self-paced and self-directed learning." (MIT Report)

Another question asked in this survey was "*What is the future direction for the engineering education sector?*' Three trends emerged from all the responses:

1. Moving of power houses of engineering programs from North America to Asia and South America due to strategic government investments and technology-based entrepreneurial talent.

2. A move towards socially relevant and outward-facing engineering curricula that emphasizes student choice, multidisciplinary learning and societal impact, coupled with a breadth of student experience outside the classroom, outside traditional engineering disciplines and across the world. Although these types of activities can be found in many institutions, the "emerging leaders" managed to make them part of a unified and integrated approach.
3. Offer the student-centered curricula at scale. The emerging leaders have figured out ways to do so.

In the following tables we have summarized the educational approach for the four cases.

Table III Educational approach at Singapore University of Technology and Design, Singapore (SUTD)

Educational feature	**Key Characteristics**
Model	• **Design and Maker based learning**: Many hands-on projects spanning a range of scale, duration and areas of focus. • **Collaborative Culture**: Flat hierarchy, start-up like atmosphere • **Multi-disciplinary approach**: Not traditional departmental silos, four pillars • **Breath of student's experiences**: in-class as well as out-of-class.
Student Selection	Candidates are expected to have strong qualifications in mathematics and physics. all shortlisted candidates are interviewed. Interviews are used to identify candidates with, "*passion for technical design, aptitude for multidisciplinary learning and a willingness to take risks.*"
Flexibility of Curriculum	*Students study a common first year and then specialize within one of four multidisciplinary pillars – Architecture and Sustainable Design (ASD), Engineering Product Development (EPD), Engineering Systems and Design (ESD) and Information Systems Technology and Design (ISTD).*
Interdisciplinary opportunities	Education is intrinsically multidisciplinary. The programs span the STEM areas and encourage students to look beyond the purely technical dimensions of engineering problems through, Humanities and Design courses.
Pedagogical approach	Design-centered active learning is the main methodology used, with an emphasis on hands-on learning and prototyping; collaboration, group discussion and problem-solving play critical roles. Some of the specialist courses and electives use "*extended lectures*" along with projects and problems.
Assessment and feedback	The first term of the program is not graded. Thereafter, students sit two–three days of exams at the end of each term. Continuous assessment linked to team projects constitute bulk of the grade.
Teaching and learning support	In the early stages 40 SUTD faculty participated in the *Teach the Teacher* program at MIT. Several training workshops were also conducted around active learning, facilitation, design-based learning, etc. The university now has a Learning Science Lab, that supports educational development among faculty.

Reward and recognition of teaching	Tenure and Promotion system mirrors that of R1 universities in the US and is primarily dictated by research productivity.
Educational research activities	*Educational research here is more prominent than at most research-intensive universities.* Faculty publish work on design education and active learning as well as evaluation of the university's curriculum and assessment tools.
Extra-curricular opportunities	Dedicated time periods are set aside for student-led extra-curriculuar learning activities. Over 90 clubs and students organizations now thrive here.

Table IV: Educational approach at University College London, UK (UCL)

Educational feature	**Key Characteristics**
Model	• **Integrated Engineering Program (IEP) Challenges:** two intensive five-week design projects tackled by incoming first-year students. Both *Challenges* are multidisciplinary and brings together students from across UCL Engineering; • **Scenarios cycles:** five-week curricular clusters, which underpin the curriculum in Years 1 and 2 of study, where students spend four weeks learning engineering theory and skills that are then applied in a full-time one-week design project; • **Design and Professional Skills (D&PS):** modules throughout the first three years of study, designed to build students' personal and professional skills; • **Minors:** specialist options for second and third year students across UCL Engineering; • **HTCTW*:*** a two-week, full-time multidisciplinary project focused on key societal challenges.
Student Selection	Candidates are now selected solely on the basis of high-school ('A' Level) grades and written submissions. In UCL Engineering, student selection is conducted on a departmental basis.
Flexibility of Curriculum	Students remain within their chosen engineering discipline from entry to UCL and throughout their degree. Students can choose minors and electives in years 2,3,4.
Interdisciplinary opportunities	IEP modules provide extensive opportunities for inter-disciplinary work. Apart from that electives are perhaps the only other courses. for students to work with peers from other engineering departments. Many of the departmental projects provide opportunities for students to work with industry, charities, schools and outside community.
Pedagogical approach	Around 40% of the curriculum is delivered through project-based experiences. The remaining curriculum is largely devoted to 'core' engineering or Design and Professional Skills modules where pedagogical practice varies by department.
Assessment and feedback	Almost all IEP assessments are summative. The net assessment work has increased with IEP but a number of novel tools have been developed for the evaluation of individual contribution to IEP project work.

Teaching and learning support	Teaching and learning support and training is provided both through the central IEP and through the College. Also the University has several programs such as UCL Arena and UCL: Changemaker that supports teaching and learning and collaborations in these areas.
Reward and recognition of teaching	Career tracks are divided into an academic track, an education-focused track and a research track. University instituted reform to develop a process for improving and formalizing the recognition and reward of teaching achievement.
Educational research activities	engineering education research capacity has grown significantly since the introduction of the IEP. Areas of particular research focus include (i) problem-based and skills-based learning; and (ii) participation and inclusivity in engineering throughout schooling, higher education and professional careers.
Extra-curricular opportunities	In addition to those linked to each engineering department, a number of student-led clubs are organized at a Faculty level, many of which focus on engineering outreach. Students from UCL Engineering are also heavily involved with the *UCL Global Citizenship Program.*

Table V: Educational approach at Charles Stuart University, Australia (CSU)

Educational feature	**Key Characteristics**
Model	• **Unique program structure:** Five and a half year long program. First year and a half is on-campus and consists of a series of project-based challenges. During the next four years students are off-campus in work-based learning environments. A unique self-directed learning mode is used where almost all 'technical engineering content' is delivered online and completed by students at their own pace. • **a professional engineering culture:** a culture of professionals in engineering training exists here which considers students to be student engineers rather than engineering students. • **embedding flexible, state of the art online learning:** extensive and efficient on-line platform that is able to deliver the engineering curriculum in "*small bite-sized chunks rather than semester-long courses, giving people freedom in how they learn.*"
Student Selection	Only engineering school in Australia that does have a threshold attainment level in mathematics for selection to the program. No academic 'prerequisites' for its intake. Two stage student selection: Candidates students are asked to respond to five questions, such as '*how do engineers contribute to society'*, '*how will you contribute to the diversity of our school*' and '*how are you academically prepared to study at CSU Engineering*'? At the next stage shortlisted candidates are invited for a 30-minute on-campus interview.
Flexibility of Curriculum	Beyond the 'core' required subjects, students choose topics from a *topic tree*, depending on their interests and their project or placement needs. Students also select which their work placement to apply for. During the final two years

	of study, students must an area of engineering and complete a branch of the *topic tree* corresponding to that field.
Interdisciplinary opportunities	Zero interdisciplinary opportunity at the curriculum level. During on-campus and off-campus students get a chance to interact with communities and professionals within and outside of engineering.
Pedagogical approach	Student-centered and experiential education through a mix of project- and problem-based learning (through on-campus *challenges* and off-campus work-placements), with self-directed study (through a network of online learning 'topics' which students must demonstrate mastery of in order to complete). A lot of emphasis on self-reflection, with students setting their own goals and reflecting on their progress, achievements and failures.
Assessment and feedback	On a weekly basis students typically to submit the following assessed components: • tests/assignments around three topics from the online *topic tree*; • written review of the teammates' contributions to projects; • self-reflection about progress towards their learning goals; • updates in their portfolio with new achievements; Each week they also receive a report on their *topic tree* progress and feedback from both their personal mentors about project challenges.
Teaching and learning support	All CSU Engineering staff receive a post- graduate certificate in teaching and learning. Topic tree material development is done with help from a commercial provider.
Reward and recognition of teaching	The promotion criteria are fairly traditional with research output as the major criterion.
Educational research activities	A number of individual faculty with global status in engineering education research are at CSU. Most of the research focus is around automated assessment and self-directed, problem-based learning. CSU is also planning to start a PhD program in engineering education.
Extra-curricular opportunities	Extra-curricular activities are similar to other institutions.

Table VI: Educational approach at Delft University of Technology (TU Delft)

Educational feature	**Key Characteristics**
Model	• **deep disciplinary knowledge:** the technical rigor of the TU Delft education is of extremely high quality • **the integration of engineering, science and design:** each program has brought together together a blend of engineering, science and design. • **an ambitious student culture of initiative and hands-on learning: a very strong culture of student-led extra-curricular academic activites has been established here. This operates independent of**

	the university's control. The goal is to apply engineering to real-world problems. • **a pioneering approach to blended and online learning:** the university is having a growing strength in on-line learning that is impacting positively on-campus and off-campus.
Student Selection	Until recently all selection was determined by a process set up by the Dutch government. Overprescribed programs in high demand has been recently allowed to set their own criteria for enrollment. So, Aerospace Engineering is one of the first TU Delft programs to introduce student selection procedure. Prospective Aero.E.. students will be selected using a four-stage process: completion of the *Introduction to Aeronautical Engineering* mini MOOC; a test designed to evaluate motivation for academic study; tests in mathematics and physics; and an assignment in aeronautical engineering.
Flexibility of Curriculum	The program is pretty much pre-prescribed. Students have very little choices apart from a minor in their 3rd year. More choices are available at the Master's level.
Interdisciplinary opportunities	Very few opportunities are available for interdisciplinary work; most of it is extracurricular in nature.
Pedagogical approach	No uniform pedagogical approach. Individual faculty determine that so it ranges from traditional lecture to project-based learning.
Assessment and feedback	Assessment method is mostly traditional in nature.
Teaching and learning support	TU Delft has a Teaching Academy. The new Teaching Academy offers professional development courses, workshops and UTQ training and 'hands-on' support for online or on-campus course development.
Reward and recognition of teaching	Academic appointment and tenure is primarily based on research productivity.
Educational research activities	Engineering education research happen in scattered pockets across the university in an un-coordinated fashion.
Extra-curricular opportunities	Over half of students participate in one or more club or society. A high proportion of these groups are focused on science and engineering and their application to society. These operate quite independently without any supervision, tutoring or involvement by TU Delft staff.

Conclusion

In this paper we have attempted to summarize information that is available regarding the different visions for Education 4.0. It is clear that the future of work and education will look quite different from what they are today. Changes in industry are happening at a very rapid pace that will require the education system to change dramatically. Literature shows that in many broad areas there is general agreement as to what the future of education should look like. However, the path to get to this changed system from where we are now is unclear. Change this time will require a paradigm shift in the education ecosystem that has operated the same way for over a hundred years and is also a system where change comes very slowly. It seems that the biggest challenge will be to develop a paradigm of education that will deliver the desired service at a scale that is needed. The four cases summarized in the paper have been successful in implementing some aspects of this quite successfully: SUTD in the area of breaking down disciplinary silos and including hands-on education throughout the curriculum, UCL in the area of Industrial projects and applications integrated intimately in the curriculum, CSU in merging on-line education successfully with practical applications and essentially flipping the entire program, and TU in harnessing a strong student-led extra-curricular program to enhance learning. These programs show how changes can be made at a larger scale. What will be required to replicate some of these successes? The answer perhaps lies in the common characteristics observed in these four programs: a strong commitment from the administration, adventurous and open-minded faculty, student buy-in, and willingness and confidence to re-design almost from a clean slate.

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