Engineering Education at the Age of Digital Transformation

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***Abstract*— During the last two decades, profound technological changes have taken place around us, supported by disruptive advances, both on software and hardware sides. An amalgamation of information, communication and AI is taking place, as well as the cross-fertilization of a wide range of concepts, referred to as the digital transformation. As a result of convergence phenomenon, the boundaries between different disciplines are eroding, necessitating a thorough discussion on what the engineering education should be like in the future. In this paper, after presenting a brief history of engineering education, the recent paradigm changes are discussed, which essentially stress that skills must prevail over degrees to deal with challenges posed by the megatrends of the fourth industrial revolution.**

***Index Terms*—Engineering Education, 21st Century Skills, Higher Education, Digital Transformation.**

I. Introduction

During the last two decades, profound technological changes have taken place around us, supported by new disruptive advances, both on the software and the hardware sides. An amalgamation of information, communication, and AI is taking place, as well as the cross-fertilization of a wide range of concepts. These changes are causing what is commonly referred to as the digital transformation, the main characteristics of which boil down to convergence and erosion. We are witnessing a convergence phenomenon, where convergence is fueling further convergence and finally laying the foundations for the emergence of more new technologies. The advances are generally at the edge of traditional disciplines. The connections between different disciplines are becoming the core of the new technologies, in a not multi-, not inter-, but in a trans-disciplinary, seamless manner. At the same time, the boundaries between different disciplines (and many other things) are eroding; what mechanical engineering is, what electrical engineering is, and, what computer engineering is, are becoming difficult to define. In fact, what engineering is and what basic sciences are (even the social sciences for that matter) nowadays difficult to define. In short, we are going through a phenomenon of convergence of different disciplines, necessitating a thorough discussion on what the engineering education should be like in the future. “If we do not change the way we teach, 30 years from now, we’re going to be in trouble” [1].

In order to be able to survive in an increasingly competitive and global market, enterprises need graduates who can manage the changes, a challenge that the engineers of the 21st-century face. The graduates of the engineering schools in the 21st century should be capable of going from technology to solutions and from solutions to operations and this requires a broad skill set. Speaking at the 2017 Times Higher Education Research Excellence Summit in Taichung, Taiwan, a similar remark was made by Prof. Sung-Chul Shin, the President of the Korea Advanced Institute of Science and Technology (KAIST). He stated that universities must embrace cross-disciplinary education and research in order to deal with challenges posed by the "megatrends" of the fourth industrial revolution. These challenges were particularly pressing in South Korea, which he described as being at a "stall point" where it can either continue developing as an advanced nation or get stuck with a "stagnant economy". "Concerning all megatrends, university reform is urgent," he added [2].

II. Historical Perspective

The necessity of change in educational approaches has been recognized by both industry and academia since a long time ago. The earliest study dates back to 1918 as the first evaluation of U.S. engineering education [3]. It is interesting to note that Prof. Mann advocates a "case" based approach (like advocated for the law practice) in his study. For example, in electrical engineering, a "dynamo" could be the "case" and the students would start with an analysis of the case for the purpose of discovering the fundamental physical and/or mechanical principles involved in its operation. This would "lead the student from practical applications by analysis to a comprehension of theory, instead of from theory to applications". How similar it is to some recent concepts!

Another study [4] that goes back well into the history begins by a review of the state of engineering education in the late 19th century and continues with a discussion of the role of European-born and educated engineers such as Stephen Timoshenko, Theodore von Kármán and Harald Westergaard. The paper then goes on to state that these "European École" engineers laid the foundations of the transformation of engineering curricula that came later.

A recent study [5], written for the Centennial Year of IEEE (Institute of Electrical and Electronics Engineers), is detailed and very informative. It lists the major shifts in engineering education that have occurred during the past 100 years as follows:

1. “a shift from hands-on and practical emphasis to engineering science and analytical emphasis;
2. a shift to outcomes-based education and accreditation;
3. a shift to emphasizing engineering design;

4. a shift to applying education, learning, and social behavioral sciences research;

5. a shift to integrating information, computational, and communications technology in education."

A. The Current Scenario

The world we live in has evolved tremendously while our education system tries to hold on to the old patterns of teaching, learning, and consequently conferring qualifications (degrees). When college is mentioned, the predominant image conjured up is a lecture hall with a member of the faculty at the front talking and students listening. Each time the bell rings students pour out of the halls and faculty rush to their next class [6]. Progress in the current system is measured by the number of hours spent on the seat, the unit of measurement is the credit hour [7-8]. Despite the fact that it is meaningless to measure seat time, education systems continue to do this. The argument put forward in [9] is in favor of reversing the traditional equation. The authors believe in ensuring that learning is constant while time could vary, thereby creating opportunities for students to accelerate learning through self-paced asynchronous programs.

We are in times when a large population of teens is tech-savvy – "digital natives" is the term used in [10] and the "net generation" in [11] – they are surrounded by computers, videogames, digital music players, video cams, cell phones, and all the other tools and gadgets of the digital age. This cohort has access to large vaults of knowledge available on the Internet; it is possible for them to self-learn concepts and skills with few clicks, which are otherwise difficult to grasp in the traditional classroom environment. Moreover, various online-academies make it possible for students to access and learn independently or with the help of peers on the net. Massive Open Online Courses (MOOC's) and Open Educational Resources (OER's) are some examples of these. Clearly, the growth witnessed in these learning formats indicates a future where more independent learning will develop and flourish.

It is observed that the rich multi-media content available on the web [12] enables a student to acquire the knowledge which barely reaches him/her in the archaic class. In recent days, much has been spoken about the way content needs to be delivered, and a lot of emphases has been placed on using technology to improve delivery. However, most suggestions do not address the possible removal of the instructor (at least for certain subjects) from the classroom, even if it is beneficial. The term 'flipped classroom' is normally attributed to the work [13]. It is a philosophy that puts the student instead of the lecturer at the heart of the learning process. There are many ways to flip teaching. The central idea is that students prepare in advance for the contact session with instructors, enabling better time utilization [14]. Technology too plays a big role in making the flipped classroom a reality. As a consequence of adopting technology for teaching, university faculty will greatly benefit, as they will have more time to spend on research and undertake more productive work.

Today, in most cases, students are able to acquire the most important knowledge about a course from sources other than the traditional lecture (e.g. MOOC's/Collaborative Learning) and are able to pass the examinations of the course without taking any formal classes. This has helped students to learn at their own pace. Mozilla is now validating such learning by awarding badges [15]. This is another useful way of letting the student progress at his/her own pace, it keeps him/her engaged and eager to move forward. For students who have the badges (that confirm knowledge), Universities could provide course waivers for a subset of courses that do not require intensive laboratory sessions or projects; as this would not affect the achievement of the program learning outcomes and also where some of the course contents overlap with other courses. While this may not be for all, it will be beneficial for a large number of qualified students whose number is steadily rising.

In addition to this, independent learning enables students who are smart in certain areas to engage themselves earlier and learn more quickly, thereby completing the course in a shorter period of time. In the work [16], the authors discuss accelerated learning programs including fast-track degrees. They argue that such programs are not meant to replace the existing traditional degree, but to provide a range of options for learners. They stress that acceleration works very well for "more able students; i.e., those of sufficient maturity, with motivation and commitment to handle the additional workload." The benefits include being responsive to the needs of employers and students, particularly those who have a specific need to graduate more rapidly. In addition, quicker graduation time for some students enables them to enter the job market at a younger and more energetic age, and thus contribute better to the economy. This will also make room for more students to enroll into existing programs and thus help to address the problem of "massification" by catering to the rapidly increasing demand to acquire university degrees. The initiatives taken in this context in several universities of US, UK, Australia, and Norway is detailed in [16].

B. Some Issues with Today's Higher Education

Can everyone get quality Higher Education (HE) today – particularly in the discipline of their choice? The answer is "yes". However, it is not possible to make quality higher education available to all with the model currently in use. Imagination and coordinated effort would be the keys to making it happen. What is being proposed towards this objective is a multi-dimensional approach involving universities, content providers, hosting companies, testing services, regulators, accreditation agencies; and other stakeholders.

To begin with, we will explore the terrain, understand the climate and chart a course. Simply put, the metaphor translates into understanding the demand for flexibility, acknowledging the lapses of the current system, and bringing key players together to implement a bold new approach to meet the academic needs of students and fulfill the economic aspirations in the 21st-century and beyond. Some relevant issues with HE today is as bulleted below, without going into the details:

- Massification
- Repetition
- Boredom
- Exorbitant Cost

- Market Needs

A preliminary worldwide survey was conducted among university students and over 1000 responses were analyzed, the results are summarized as follows:

- Over 40% indicated that they would like to learn on their own and on their own time schedule,
- About 55% preferred to learn using multimedia tools as opposed to printed material,
- Over 75% felt they already had the knowledge of some of the basic courses taught at their university,
- Over 65% of these respondents wanted to be examined for a waiver before the start of the course, and
- Over 60% preferred learning from peers and from supplied audio-visual material independently as opposed to lecture/note-taking.

When asked if they had used any of these for learning:

- 97%+ responded that they had used Google
- 93%+ had used YouTube
- 29%+ had used Khan Academy, and
- 31%+ had used Coursera

Finally, when asked, if they would attend class if attendance was not mandatory:

- 26% said they would never go to class at all, and
- 74% said they would attend only interesting or useful sessions.

What is deducted from the above survey is that there is a need for both accelerated and independent learning. In addition to resolving other issues faced by HE today, course waivers may also be a good approach to encourage independent learning, thus shortening the duration of existing courses that are needed to complete degrees.

III. Future of Jobs and Universities

Throughout most of the 20th century, we have been witnessing a changing nature of work and careers. In the past, people used to spend their lifetimes in one or two organizations. But since the 1980s, as firms are under pressure to downsize and outsource, work has become more precarious. People today construct their careers across organizations. Not only are people crossing organizational boundaries in the course of their careers, but they also go over the occupational boundaries. A recent report [17] of the World Economic Forum (WEF, the organization behind DAVOS meetings) quantifies this tendency by the prophecy that by 2022 "no less than 54% of all employees will require significant reskilling and upskilling." Here, what are meant by reskilling and upskilling are "learning new sets of competencies to transition to a completely new role" and "learning new competencies to stay in current role, due to the change in skills required, or adding certain competencies for career progression" respectively. A further prediction is that out of these, 35% will need additional training up to six months, 9% between six to 12 months for reskilling, and 10% more than a year to acquire additional skills. This may cause some alarm in some enterprises, however, as it is stated in the report; "in order to truly rise to the challenge of formulating a winning workforce strategy for the Fourth Industrial Revolution, businesses will need to recognize human capital investment as an asset rather than a liability."

Recognizing the shortcomings of the educational system, President Obama initiated a drive for STEM education [18] where STEM stands for science, technology, engineering, and math collectively. Despite the initial enthusiasm, it was soon realized that STEM inherently meant focusing on the right side of the brain rather than the left side, which is believed to be more creative and artistic (most recent studies indicate that this is a myth). It was perhaps because of the recognition that soft skills would require more than STEM subjects that an expanded version of the abbreviation was offered by some in the form of STEAM, where A stands for art. After all, as Picasso has once stated, "All children are artists. The problem is how to remain an artist once he grows up."

A recent argument is that given the present rate of technological and societal changes one just cannot teach it all! One suggestion that has already received widespread acknowledgement is that the traditional four-year bachelor degree program does not provide enough time to cover the fundamentals and at the same time provide training in specialized areas [19]. Rethinking the college curriculum and refocusing it on "soft" skills (as will be discussed later) could allow students to finish their degrees sooner. They could then move on to graduate school or the workforce. Giving credit for advanced study in high school can help for early graduation.

An extreme argument is that “the degree is doomed….The value of a college degree has been in question since the Great Recession, but there have yet to emerge clear alternatives for the public to rally around” [20]. In a report by the Economist Intelligence Unit (EIU) [21], it is stated that “lack of time within a strictly regulated curriculum is the biggest barrier to teaching 21st-century skills (49%), while the third most-cited reason is similar: the strict requirements by education authorities that classes focus on literacy and numeracy (30%).”

It is clear that higher education is, in the age of disruption, in the midst of a dramatic, disruptive changes. It is being unbundled. As one Nobel Prize-winning economist is reputed to have ominously remarked, "Now school does not mean you will learn; learning does not mean you will have the skills for the labor market, and having the skills does not mean you will have a job - it's a more complex route." As careers become more fluid, we need alternative ways of training and retraining workers (reskilling and upskilling) for growing job areas. Otherwise, market forces will make sure that the void is filled. We have already started seeing the first signs of this, there is a rise of alternative credentials, in the belief that in the age of disruption, the traditional credentials are not only unnecessary but sometimes even a liability. The worldwide popularity of recent players like the Fullbridge Program (http://www.fullbridge.com) and coding boot camps is an indication of the shortcomings of the higher education institutions and the hunger for reskilling! It should be noted that these credentials do not have to replace college. But working adults will increasingly rely on such alternative credentials in the course of their careers to attain the skills they need to remain

employable or enhance their employability or to pursue their passions/callings etc.

IV. Characteristics Of The Most Recent Generation, Gen C

Social generations are cohorts of people born in the same date range and who share similar cultural experiences. In the Western World, the list of generations as listed in Wikipedia [22] start with the Lost Generation, the Greatest Generation, the Silent Generation, Baby Boomers, Generation X, Millennials (also known as Generation Y) and Generation Z. Gen Z is also referred to as Gen C due to its prominent characteristics. Some argue that Gen C does not refer to a particular age group, but to a mindset. One could be 15 or 75 to be a member of Gen C. Its members have one big thing in common: they are digital natives and exceptionally tech-savvy, staying connected all the time. Additionally, they are Communicating, Content-centric, Computerized, Community oriented and Clicking. This generation is considered to be the one that shapes everything; most market decisions are focused on them. It will not be an exaggeration to state that most innovations are due to them.

V. Paradigm Changes In Basic Skill Sets

In science and philosophy, a paradigm is defined as a distinct set of concepts or thought patterns, including theories, research methods, postulates, and standards. In the educational arena, there have been a number of important paradigm changes, some in the contents of education and some in the skills that the graduates should have. With the rise of the ICT (information and communication technologies) a heap of new science and engineering subjects emerged. The reaction of the college professors was generally "our graduates might need to be equipped with this topic; so, let us include a compulsory or selective course into the curriculum." However, as the ICT revolution gained steam, it was soon realized that it would be impossible to include all that is "new" into the curriculum. Consequently, came the paradigm shift from "just-in-case teaching" to "just-in-time learning." Parallel to this, the concepts like "life-long-learning," "learning by doing," "teach to learn" and so on became the common talk.

At the beginning of the 20th century, the basic skill set that a job seeker needed to have was considered to be **3R**s, i.e. **R**eading, w**R**iting and a**R**ithmetic. With the start of the convergence and the growth of big data, **3R**s were replaced by **3S**s, i.e. **S**earching, **S**haring and **S**imulation. Considering the 3Vs (volume, variety and velocity) of big data, the first skill is necessary for "just-in-time learning," i.e. to find the "document" (in whatever form) to learn from. The second S indicates that most projects require working in a transdisciplinary team, with the members of which one has to share knowledge. The last S refers to that most of the work will be done in front of a computer screen, using simulation tools.

In the report [21] by the Economist Intelligence Unit (EIU), only 34 % of executives surveyed reported that they are satisfied with the level of attainment of young people entering their companies and 52% stated that a skills gap is hampering the performance of their organization. On the other hand, an OECD survey [23] came up with the conflicting finding that 21% of workers reported feeling over-educated for what they do. The logical deduction is that the educational ways we have been following are teaching the workforce the wrong things, and that a fundamental change is required to facilitate the development of technical skills, cognitive and non-cognitive skills, commonly referred to as "soft skills." This includes the "**4C**s of twenty-first century learning", which are **C**ritical thinking, **C**reativity, **C**ollaboration, and **C**ommunication. These are perhaps the inherent characteristics of Generation C, and may mostly be self-acquired as only a minority of 18 to 25-year-olds report that their education provided them with the skills needed in the workplace. A large majority (77%) is confident or very confident about their career prospects [18]. Most of them consider that that they have become good or very good at the skills listed in the questionnaire without receiving much formal education in them.

Going over the individual Cs of the 4C, the third and the forth (Collaboration, and Communication) corresponds to Sharing skill of the 3Ss. When there is so much talk about robots taking over most jobs, it is perhaps a relief that the first two, i.e. Critical thinking and Creativity, are the areas where human beings still hold a considerable advantage over intelligent machines.

The remarks of above stresses skills above degrees. "Skills not degrees may be the reality of the future" [24]. Similarly, in a recent report by WEF, eight critical characteristics in learning content and experiences are defined in "Education 4.0" to be able to cope with the challenges of Industry 4.0 [25]:

1. Global citizenship skills,
2. Innovation and creativity skills,
3. Technology skills,
4. Interpersonal skills,
5. Personalized and self-paced learning,
6. Accessible and inclusive learning,
7. Problem-based and collaborative learning,
8. Lifelong and student-driven learning.

VI. Conclusions

As has been stated over and over again, we are going through tremendous changes in our times, so much so that it is thrilling, exhilarating, and exciting, as well as perhaps scary. According to IBM, the build out of the "internet of things" will lead to the doubling of knowledge every 12 hours. On the other hand, the half time of knowledge is decreasing all the time, faster in engineering than basic sciences. How long can human beings cope with these disruptive changes? Should machines come to our rescue where we fail? Not in the form of replacing us, but helping us? Artificial General Intelligence has already entered the educational domain especially in the form of intelligent tutoring systems, intelligent learning environments, adaptive hypertext systems, some computer-supported collaborative learning systems, etc. Although the field is still in its infancy, it will not be very long before a flight simulator can reconfigure itself both in its software and the apparent hardware (made

possible by augmented virtual reality) according to the ECG and other signals received from the pilot-to-be. This will be a human-in-the-loop approach.

Finally, the erosion of boundaries has already been stated to be an important characteristic of the 21st century. This will perhaps lead us to Nepantla [26]; the liminal space, the in-between, and the borderlands from which novel insight and inspiration emerges. Such a transdisciplinary scholarship will remove the boundaries of what engineering encompasses to enrich the academic discourse of our profession.

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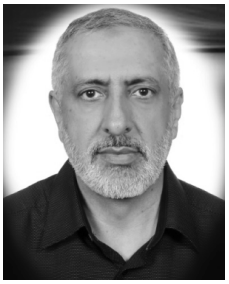

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