Developing Skills for Industry 4.0: Challenges and Opportunities in Engineering Education

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Abstract*—This Research to Practice Work in Progress Paper focuses on the Education 4.0 Framework, based on built-in skill development mechanisms and innovative learning pedagogies related to Active Learning approaches. Practicing engineers are increasingly expected to act as boundary spanners who manage and participate in diverse interdisciplinary global teams, leverage cultural differences, and draw on expert knowledge from multiple fields and specialities to translate competing stakeholders' needs into practical design solutions. This demand for a holistic type of engineer stems from the requirements of the Fourth Industrial Revolution: engineers who assume the role of leaders can integrate knowledge and work seamlessly across intellectual, social, and cultural challenges. Our exploratory study aims to identify the implications for practice, challenges, and opportunities in Higher Education. More specifically, we look at two engineering programs of two universities, one located in Mexico and the other in the United States of America. Both universities have implemented massive Experiential and Challenge-Based Learning efforts with industry and external organizations as educational partners to immerse students in real-life contexts. The methodology used was qualitative-experimental, involved more than 120 students, and included a post-test for skills assessment with different instruments such as rubrics, questionnaires, interviews, and surveys. The preliminary findings of this work-in-progress study reveal that the role of Higher Education professors in the training of future engineering professionals within the Education 4.0 Framework has different degrees of complexity related to the cross-border nature of educational innovation, that requires the commitment and alignment of multiple actors: students, professors, organizations, and industry.

***Keywords*—educational innovation, higher Education, education 4.0 skills, STEM education, industry 4.0**

I. Introduction

International organizations such as the World Economic Forum and the Organization for Economic Co-operation and Development posit that the preparation of the future workforce should be based on eight pillars: the built-in mechanisms for skills adaptation (global citizenship; innovation and creativity; technological and interpersonal abilities); and the leveraging innovative pedagogies for learning (personalized and self-paced; accessible and inclusive; collaborative; lifelong and student-driven) [1], [2]. Curriculum design based on STEM education has varied over the years. Considering stakeholders' interests for the generation of a workforce better adapted to the real world, the evaluation of the curricula has been based on measuring the students' success. Although this success is subjective and context-dependent, in the '50s and '60s, there was a quantitative measurement system based on scores of exams and knowledge tests; from the '70s to the '90s, persistence and factors such as motivation and goal pursuit [3]. However, unrepresented students usually did not meet the established standards with these theories. Those situations lead to the urge for institutional change and ensure the success of all students [4]. Between 1995 and 2008, disseminating curriculum and pedagogy, developing reflective teachers, enacting policy, and developing a shared vision were the most relevant topics of practices in STEM [5]. In recent years, a rapid change has been seen in STEM education, emphasizing goals, policy, curriculum, evaluation, and assessment; so fast that some researchers suggest that a new revision will be necessary every five years [6]. Regardless of the purpose, nowadays the STEM curriculum is based on interdisciplinarity and skills development. On one hand, interdisciplinarity, in its case, entails the difficulty of measuring it. This interdisciplinarity must be intentional and specific, for which explicit strategies, feedback, and continuous improvement are required.

On the other hand, being equitable (inclusive and fair) and diverse (origin and language), sustainable and digitized are the main characteristics of STEM curricula today [7]. Skills for sustainability, with its pillars, namely economy, social, and environment, represent an opportunity to generate professionals who ensure enough production with fewer resources and prepare underprivileged students for a better

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job in this transition. On the other hand, digital skills are some of the most promising in the workforce demand, as they will put employees in charge of their learning [8]. In this sense, quantitative mapping tools and skills acquisition are necessary.

A change in the curriculum includes a change in the mentality of the organizations, which must also maintain sustainable costs, effective financial planning, skilled staff, increased industrial partnerships, advanced infrastructure, and the inclusion of non-academic professional credentials [9]. However, the readiness of educators, management staff, and students was an issue exacerbated by the pandemic. This has given rise to the so-called "quantum leap," transitioning from engaging in the curriculum to instilling success-oriented attitudes and behaviours [10]. To overcome those difficulties, third-party accreditation recommendations (QS, STARS); political, economic, social, technological, legal, and environmental (PESTLE) analysis, or strengths, weaknesses, opportunities, and threats (SWOT) analysis with analytic hierarchy process (AHP) addressing the viewpoints of stakeholders is recommended for universities to develop curricula and educational systems with a greater context.

With the emergence of Industry 4.0 with its numerous benefits, it is necessary to enable the new workforce. The need for practical expertise and the implementation of digital technologies empowers future Industry 4.0 workers. In this regard, universities must adapt their educational programs to the opportunities and challenges this poses for a more sustainable future. Our exploratory study aims to identify the implications for practice, challenges, and opportunities in Higher Education Institutions (HEI) and answer the following research question (RQ):

What kind of engineering education will we be teaching in 2030?

The study looks at two engineering programs of two universities, one located in Mexico and the other one in the United States of America. The project analyzes the efforts of Experiential and Challenge-Based Learning with industry and external organizations as educational partners to immerse students in real-life contexts.

II. THEORETICAL FRAMEWORK

Industry 4.0 is a new trend in industrial production that emerges from the mixture of internet-of-things and smart objects. It results in a production model that contains modular and efficient manufacturing systems. The potential of this framework for manufacturing is the ability to craft individual products in a batch size of one while maintaining the economies of scale of mass production. Industry 4.0 demands man-machine interaction, mutual learning, and technological connectivity [11]. This paradigm change in the industry, together with a global trend of highly competitive and evolving labour markets, demands a new cohort of professionals who can constantly transform and change to remain active in the job market.

Different authors have discussed the need to restructure academic curricula to teach new competencies that enable students to thrive in the demanding context of Industry 4. 0. In their 2021 study, Kargas *et al.* differentiate these competencies into two groups: skills and knowledge [12]. On the one hand, the knowledge comprises Information and Communication Technology (ICT), Software Development, Automation, Algorithms, Data Analysis, and General Systems Theory. On the other hand, the skills are the soft factors of the individual, which include adaptability, flexibility, leadership, receive-and-give feedback, self-organization, teamwork, creativity, communication, interdisciplinarity, self-management, innovation, initiative, and problem-solving [13]. Other authors, such as Hernandez-de-Menendez *et al.*, define the hard factors as technical competencies and divide soft skills into three categories: methodological, social, and personal competencies [11]. These soft competencies include motivation, innovation, decision-making, flexibility, tolerance to ambiguity, teamwork, and communication, among other related items.

Another important soft skill for the 4.0 Industrial revolution is digital transformation, which is the successful integration of technology with all business areas. As technology becomes pervasive in our daily lives, students need to understand how technology is created, how to operationalize it, and how it adds value to customers and employees of each organization. If a company cannot use technology in its business, it can become obsolete quickly. Furthermore, digital transformation generates the need for a re-skilling of the workforce [14].

Leadership and entrepreneurship are relevant soft skills that engineers must develop to be competitive in this rapidly changing work environment. ABET (Accreditation Board for Engineering and Technology) declared seven student outcomes for the engineering programs, including “an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives” [15]. Moreover, engineers must have the ability to acquire and apply new knowledge, identify needs, and propose solutions to develop and transform our society.

One of the most demanded skills for industrial development today is sustainability, understood as the sum of skills, soft and technical, a transversal set to be acquired and obtained along the training path that promotes a rational consumption of resources [16]. The Conference of the Parties (COP) of the United Nations concluded with a profound reflection on how Education could contribute to the Sustainable Development Goals (SDG) and published the report: "Sustainable Development begins with Education. How can Education contribute to the proposed objectives" [17]. Thus, the vision and responsibility of Education were projected concerning the fulfilment of the SDG and thus ensured an inclusive, equitable, and high-quality Education. The objective is to promote, through various educational techniques (mainly experiential learning) opportunities throughout life, where problems of poverty, nutrition, resilience, peace, justice, health, inequality, use of water, energy resources, economic growth, urban development, and environmental protection are studied and recognized.

In general, the sustainable development of a society depends on Education. It must be said that none of the SDGs could be achieved without the effect of Education since they all imply a change in mentality, attitudes, skills, and behaviour, which does not develop spontaneously, but instead has an effect or result from Education, from the cradle to the end of a person's days, in the different contexts in which it takes place. For this reason, within the Industrial Revolution 4.0, Sustainability Education has an essential role. Industry 4.0 is a new paradigm that demands adapting our educational models to achieve its full potential. Our new model should be able to teach not only hard competencies but also soft ones, including Leadership, Digital Transformation, and Sustainability.

III. Materials and Methods

Both HEI have been implementing massive Experiential and Challenge-Based Learning efforts with industry and external organizations as educational partners to immerse students in real-life contexts. The methodology is qualitative-experimental, involving more than 120 students and including a post-test for skills assessment with different qualitative instruments.

A. Tecnologico de Monterrey, Mexico

Tecnológico de Monterrey has been working on a new educational model focused on competencies development by immersing students in authentic contexts to solve relevant challenges for industry and our community. Tec21 Educational Model has four main pillars: Challenge-Based Learning (CBL), flexibility in when and where the educational experience takes place, memorable students' experience, and inspiring up-to-date faculty. For the School of Engineering and Sciences, it has been an excellent opportunity to link each engineering course with an educational partner (industry, organization, or research center) that opens its doors to engage students in significant problems and contexts to collaborate, where the students and faculty propose innovative solutions. One of the didactic strategies to develop competencies experientially is CBL, which has a higher degree of uncertainty, implies multidisciplinarity, and has changing participation roles between students and teachers. Since 2019, the Tecnologico de Monterrey has fully implemented the new Tec21 Educational model with CBL, and the results, so far, have indicated that it is essential in the development of job skills of the Industrial Revolution 4.0 [18]. For instance, a group of engineering students from the Mechatronics, Computer Science, Business Informatics, and Robotics programs engaged in a digital transformation CBL experience for one week (i-Week) with an automotive company and developed significant contributions to the challenges presented by the educational partner [19]. Similar exercises have also taken place with senior Mechatronics and Biomedical students, where internal (faculty) and external (industry) evaluators observe students working on a particular challenge and give them constructive feedback on their soft skills [20]. With this interaction, students become familiar with an instrument typically used for recruitment processes, the Assessment Center. On the other hand, companies identify potential talent among the senior students and strengthen their relationship with the professors, sharing perspectives and experiences.

B. University at Buffalo, United States of America

At the University of New York State, no single program encapsulates students' experiential learning and active learning. Instead, each campus and school operate autonomously and independently. Nevertheless, the common goal is to connect the classroom to the real world. Interestingly enough, at the University at Buffalo, active learning can occur in both academic and extracurricular activities [21]. Outside the classroom, active learning is part of a student's life–as most students live on campus. Skills developed here are leadership, sustainability, and interpersonal competencies. These programs include career peer coach, orientation leader, Introduction to Peer Education, diversity advocates, student affairs mentoring program, leadership experience, etc. On the academic side, the School of Engineering and Applied Sciences offers programs to help students develop professionalism and a practical perspective of their majors. Such programs encourage students to "engineer today" while fostering continuous Education. For example, the Tinkering program is a student-led, hands-on practice where students can use reverse engineering and digital tools to learn while solving problems [22]. These labs are supported by faculty and staff to ensure that the connection between knowledge and practice takes place. Another program is Engineering Intramurals, an extracurricular, problem-based engineering activity that provides students with a "real-world" learning experience. Capstone design projects are vital to experiential learning at UB and internships and Co-Ops [23]. In addition to these programs, there is a Project-based collaboration network–the Experiential Learning Network (ELN), where students share their experiences, success stories, and challenges. There is a community of support and showcase of students' accomplishments.

IV. Findings and Discussions

The preliminary findings reveal that the role of Higher Education professors in the training of future engineering professionals within the Education 4.0 Framework has different degrees of complexity related to the cross-border nature of educational innovation, that requires the commitment and alignment of multiple actors: students, professors, organizations, and industry.

In the CBL strategy, challenges are designed, articulated, and adapted according to the creativity of the professors, who are committed to strengthening their competencies in preparing challenges to solve real-world problems [24]. Challenges enter a cycle of continuous improvement to adapt to the circumstances of the world's educational reality, proposing motivation to provide solutions based on scientific knowledge. CBL's perceived value also imparts soft skills and competencies to resist frustration and uncertainty with the Education 4.0 paradigms [25]. As professors become designers, coordinators, advisors, and evaluators in the CBL model, guidelines have been developed, and professors also had to be trained to communicate effectively and efficiently with students, transmit knowledge and evaluate the acquisition of skills. CBL experiences have shown that students' knowledge gain is higher than in the traditional format [26]. Some challenges immerse the students in real-life challenges of world-leading companies where company members and teachers design challenges. Professors and training partners assess students' competencies acquisition in diagnostic, formative, and summative stages, considering elements such as multidisciplinary and complexity in a quantitative and qualitative, making evaluation rubrics and checklists the preferred instrument manner [27].

CBL application in Tecnologico de Monterrey has passed through many phases, where students and teachers had to adapt. The open innovation paradigm has pushed the academic community to embrace relations with society and stakeholders. As the Tec21 educational model is young, measuring impact aspects is needed to continue this innovation. According to Coursera's Campus Skill Report 2022 [28], Mexico has "an expanding higher education system that needs to be aligned with the needs of the labour market." This report, which explores skills trends among students worldwide, identifies the key steps higher education institutions can take to improve student employability. The report indicates that business skills, such as organizational development, people development, and negotiation, attract many students in Mexico who could benefit from applying these skills in job-relevant internships and practical projects. In addition, human skills such as adaptability, emotional intelligence, resilience, creativity, collaboration, and human learning create a strong foundation for students to learn and grow.

Another exciting aspect of CBL in Tec de Monterrey is that it can be an approach to a socially-oriented education. For example, in a recent study, CBL was employed to increase the awareness of cultural heritage. As a result, students evaluated the course with high scores (>9.57/10) and made comments like: “It is a very valuable way to raise awareness”, “I would recommend [the course]”, “a complete professional challenge”, “a unique experience [that] exceeded my expectations” [29].

Experiential learning, active learning, and, most importantly, interdisciplinary learning have been recognized at the University at Buffalo as effective strategies for propagation, scaling, and translating engineering education into practice. Accordingly, the university created a new department of Engineering Education in August of 2018. The department's goal is to provide excellent, accessible, and inclusive Education in different contexts: graduate and undergraduate students of any engineering field and graduate and undergraduate students specifically interested in engineering education. The goal is to disseminate new knowledge pertinent to the Education of engineers. More specifically, to improve the engineering education system in the United States that provides knowledgeable, competent, and qualified engineers for the demands of Industry 4.0. Success is tangible and can be assessed to the extent that the higher education programs become fully inclusive so that the engineering population matches the diversity in the general population.

Regarding the RQ we posed at the beginning of the study -on the type of Education towards 2030-, we consider that the Industrial Revolution 4.0 has set several objectives. Still, circumstances like those experienced in the last two years with the COVID-19 pandemic have alerted us that we are not yet prepared for a 100% digital education, neither in physical nor human resources [30]. Although both institutions were well equipped and had the infrastructure to switch from in-person to remote instruction, not all students were prepared to change the face-to-face to remote learning abruptly and had, at that time, the specific skill to cope with the situation: (i) self-regulation and time management, which enable students to motivate themselves; and (ii) stay on schedule, which enables students to complete assignments on time. As a result, some students fell behind, dropped courses, or took academic leaves.

CBL, experiential, active, and interdisciplinary learning have been helpful in the development of hard and soft skills in the students, regardless of the impact of the pandemic. However, much is left to be done to measure the success of the different strategies in developing the skills and how to equip the professors better to teach them. This work in progress aims to compare the system implemented and how they can be better implemented.

One major challenge comes in transferring the outcomes of Education to society and making society more interested in basing its development on Education. As these interactions grow stronger, students will be able to develop more of the needed skills. However, to provide such interactions, this study aims to determine the conditions to allow it and provide guidelines about how it can be done effectively.

Engineering Education has the responsibility of training specialists with a global vision and preparation for future challenges, which in some cases are emergent challenges to be solved immediately or in the short term, and many of the problems to be solved are reflected in the SDG [16]. If we meet the SDG agenda, we will probably be able to talk about a promising future. If not, perhaps we will not have where to develop more engineers! We still have time; therefore, Engineering Education must be a fundamental axis in the understanding, awareness, and action for sustainability by providing the necessary skills with changes in the curricula and the way we teach.

V. Conclusions

The Fourth Industrial Revolution requires engineers to take on the role of leaders, have the ability to integrate knowledge and work seamlessly across intellectual, social, and cultural challenges. This ongoing study analyzes the Education Framework 4.0, based on integrated skills development mechanisms and innovative learning pedagogies related to Active Learning approaches. The study is currently carried out in two engineering programs of two universities, one located in Mexico and the other in the United States of America. The qualitative-experimental methodology has been carried out by comparing experiential and challenge-based learning experiences in projects with industry and external organizations as educational partners to immerse students in real-life contexts. The preliminary results of this work-in-progress study reveal that the role of Higher Education teachers in the training of future engineering professionals has different degrees of complexity related to the flexible nature of educational innovation, which requires commitment and alignment of multiple actors: students, professors, organizations, and industry.

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