Socially-Oriented Interdisciplinary STEM Education Framework

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***Abstract*— In 2021, a group of 16 experts in STEM education, social sciences, humanities, and arts started an interdisciplinary collaboration to conduct research in education. The main objective of the group is to foster a socially-oriented interdisciplinary vision in STEM education to meet the challenges of the 21st century through interdisciplinary education that promotes diversity, equity, and inclusion. That is how SOI-STEM (Socially-Oriented Interdisciplinary STEM) Education Research Group was born. The work of this group focuses on 5 main research lines: students' active participation in the learning process, paradigm shifts in education, urban science, data science in education, and diversity, equity, and inclusion. The work of this group aims to have a positive impact on our community by addressing social and relevant challenges through education for the development and well-being of our society.**

Keywords*— *Higher Education, Educational Innovation, STEM Education, Interdisciplinary, Socially-Oriented

I. INTRODUCTION

The European Commission highlights the importance of improving societies' understanding of science and technology and the necessity to improve the inclusion and participation of all individuals in science-learning contexts [1]. Likewise, the United States National Science Foundation (US NSF) supports projects investigating the best ways to learn Sciences, Technology, Engineering, and Mathematics (STEM) effectively in four main areas: STEM learning, learning environments, broadening participation, and workforce development [2]. The science education research literature points out that university students, who will eventually become engineers, researchers, science-oriented entrepreneurs, and active citizens, often have difficulties engaging with STEM content [3], [4]. Some studies suggest that the inclusion gaps in STEM learning and skills are more prominent in the Latin American context [5].

The United Nations Educational, Scientific and Cultural Organization (UNESCO) report is an essential reference document for governments, engineering organizations, academic and educational institutions, and industry to forge global partnerships and catalyze collaboration in STEM to meet the 17 Sustainable Development Goals (SDGs) [6]. This document shows how equal opportunities for all are crucial to ensuring an inclusive and gender-balanced profession that can better respond to the shortage of STEM workers to implement the SDGs. The strategies and case studies will guide us in our research on transforming STEM education to enable Generation Z professionals to meet future challenges. The report highlights the global effort required to address region-specific disparities while also summarizing STEM trends in different world regions, emphasizing Latin America [7]. Through the description of case studies and innovative approaches and possible solutions, the report reveals why socially oriented STEM research is crucial to sustainable development and vital to addressing basic human needs. Some of these needs are alleviating poverty, supplying clean water and energy, responding to natural disasters, building resilient infrastructure, and closing the development gap—many other actions related to diversity and inclusion address urgent challenges facing humanity and the planet. Some authors mention the possible benefits of increasing the emphasis on prosocial behavior to reinforce environmental education [8].

The OECD (Organization for Economic Co-operation and Development) international report states its vision in Education towards 2030 as being committed to helping every learner to develop as a whole person, fulfill their potential and help to shape a shared future considering the well-being of the people, communities, and the whole planet [9]. It emphasizes the need for instructors and students to develop a wide range of cognitive, social, and emotional competencies called 21st Century Skills [10], [11]. These competencies make up a modern form of literacy, digital literacy, which is critical for training, learning, upskilling, and reskilling with digital technologies in today's virtual education environments. Education in the Fourth Industrial Revolution identifies four skills and four learning characteristics of high-quality learning, the Education 4.0 Framework [12].

Education 4.0 is changing how today's young students will live, work, and interact during their careers in the future. Therefore, technological advances should act as enablers in the reinterpretation of cognitive theories and teaching techniques for development. Our challenge as an education research group is to employ innovative, virtual, and technological tools that boost socially-oriented interdisciplinary STEM. Moreover, challenge students to solve complex problems using creative solutions, appealing to the extensive use of their digital literacy skills [11], [12].

II. METHOD

In 2021, a group of 16 experts in STEM from the Tecnologico de Monterrey were selected and invited to apply to belong to the research group based on their individual publication record on education research. They belonged to different schools (Faculties) of the Institution and were specialists in social sciences, humanities, engineering, and arts. This interdisciplinary group of experts had the goal to conduct research in education, in order to foster a socially oriented interdisciplinary vision in STEM education to meet the challenges of the 21st century through interdisciplinary education that promotes diversity, equity, and inclusion.

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That is how SOI-STEM (Socially-Oriented Interdisciplinary STEM) Research Group was born.

As pointed out, SOI-STEM-RG has 16 members from the following Schools (Faculties) within our university: Engineering and Sciences; Architecture, Art, and Design; Medicine and Health Sciences; Humanities and Education; and Social Sciences and Government. Our group has diverse expertise in different disciplines: physics, education, data science, urban science, computer science, logistics and supply chain, electrical engineering, educational innovation, smart materials, industrial design, bioengineering, artificial intelligence, statistics, and mathematics. SOI-STEM also has a diverse group of researchers in terms of their career maturity, combining the fresh ideas and the skills in using technological tools from the young researchers and the experience and knowledge from researchers with a more solid trajectory. The main elements of our research group are:

- *Socially-oriented.* We are convinced that we can address complex global challenges through education. As the global population grows rapidly, we observe a rising inequality, a constant fight over resource allocation, and how the environment suffers with our behavior. Education is a powerful tool to shape conscious professionals committed to contributing to our world´s well-being and sustainable development.
- *Interdisciplinary.* Collaboration between members from different backgrounds and disciplines brings complementary skills, knowledge, and perspectives to have a bigger picture and a more inclusive outlook. It is increasingly important for professionals to fully develop interdisciplinary skills with a social orientation since their profession's exercise requires that they comply with the required disciplinary and ethical obligations declared by most international associations. Professionals also require the criticism and creativity necessary to flourish as an individual in a global society and successfully face the changing environment of volatility and ambiguity.
- *STEM Education*. It is important to recognize Science, Technology, Engineering, and Math as cross-disciplinary competencies and tools not exclusive to engineers and scientists. With the digital transformation that our world is facing, STEM education has a variety of applications in non-STEM fields. Our interdisciplinary group allows us to break the paradigm that STEM competencies are only for scientists and engineers, enabling us to reach different disciplines and work with specific projects to implement useful and efficient applications. Although it has been considered to include Arts as another main area of knowledge, this work will focus on describing what has been achieved so far in the STEM areas.

The work of this group focuses on five main research lines: students' active participation in the learning process, paradigm shifts in education, urban science, data science in education, and diversity, equity, and inclusion (DEI) [13]–[16]. The work of this group aims to have a positive impact on our community by addressing social and relevant challenges through education for the development and well-being of our society.

The research group consists of three levels of researchers: Full, Associate and Adjoint, with the Full being the leaders of each line of research. Research teams are formed with the associates and adjoints and projects are created that attack topics to be investigated that can provide knowledge about new teaching techniques, evaluation or approach the solution of a social problem through education. Each project has 7 phases of development: 1) Diagnosis, 2) Problem approach, 3) Experimental design, 4) Execution, 5) Analysis of results 6) Application of the conclusions in the educational structure (curriculum, program, technology, etc.) and 7) Writing and publication of the findings to have resonance beyond our educational institution and to be able to influence educational systems around the world.

Stages 1 to 3 will be carried out prior to the courses, so that their structure and the students who take them can serve to obtain the necessary data to test the hypotheses proposed. Each educational intervention will have an objective, and teachers will have to design the measurement instruments and evidence (questionnaires, surveys, focus groups, exams) necessary to accept or reject the hypothesis. Each educational intervention must have the informed consent previously filled out by the students or responsible adults, as the case may be. The results obtained will be completely anonymous. Meanwhile, the measurement instruments (rubric, for the most part), will be designed in a collegiate manner, so that the adoption of the designed strategies is more easily implemented by other teachers in the same areas of study. This adoption is supported by the Tec21 educational model [13][17].

The SOI-STEM education research framework is also aligned with the following Sustainable Development Goals (SDG): 4. Quality Education, 5. Gender Equality, 8. Decent work and economic growth, 10. Reduced inequalities, 11. Sustainable cities and communities, and 13. Climate action as is shown in Fig. 1.

III. Education Research Framework

SOI-STEM education research framework encompasses five research lines:

A. Students' active participation in the learning process

This research line creates and promotes engaging strategies in the learning process to foster attention, motivation, and higher-level critical thinking skills resulting in a meaningful learning experience. There is an indissoluble interrelationship between Education and Society [18]. Education has always been a very important engine for the evolution of society. On the other hand, social conditions have significantly marked the ways of teaching, including many of the skills that students must train, should be explicitly developed in the study programs. How does education modify/affect/shape society? And how does society modify/affect/model education? Let's see, first of all, it is not difficult to notice that many of the tools that we use today in daily life in society are the product of educational progress in various areas of STEM, for example, the use of the internet, computers, digital programs, technological applications, mobile phones, the development of vaccines, health protocols, the use of molecular genetics, and much other scientific knowledge are the product of the advancement of the STEM areas and whose products transform today's society.

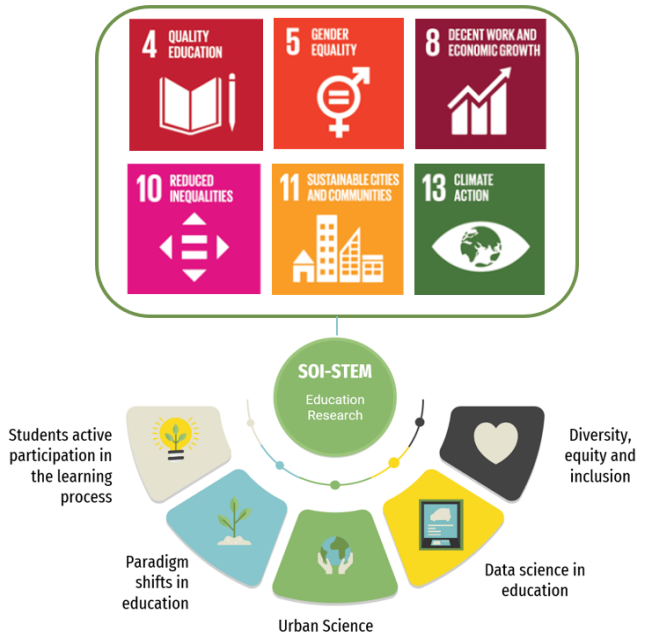

Fig. 1. SOI-STEM framework.

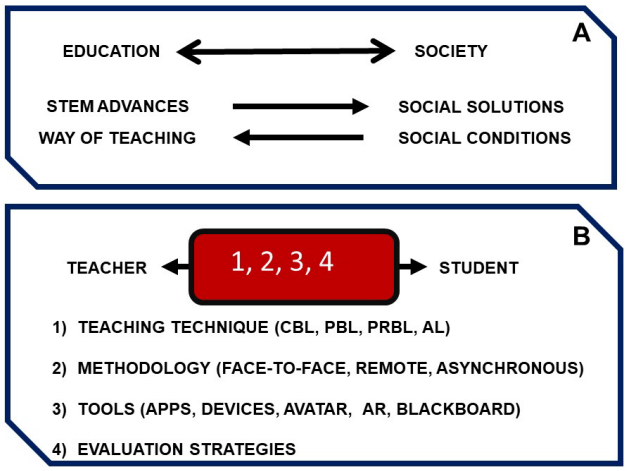

Fig. 2. Relationship between Education and Society. A) Advances in STEM education affect/shape/determine many aspects of society and have solved pressing problems. B) The "black box" of the teaching-learning process consists of at least 4 elements.

The advancement in all areas of society (economic, social, cultural, sports, industry, agriculture, energy, health) depends largely on educational progress and STEM trends that are being developed in response to an explicit need of society, as is shown in Fig. 2A. On the other hand, if there is a social situation that substantially modifies daily life, it can modify the way of teaching. The most vivid example was the advent of the COVID-19 pandemic due to the SARS-CoV2 virus, which kept teachers and students at home and implied a sudden change in the educational model, as is shown in Fig. 2A. The classes had to change to be remote, synchronous or asynchronous, the ways of evaluating changed and in general the social conditions determined the way of teaching [19], [20].

That is why in the SOI-STEM research group, one of the research lines is to analyze the teaching-learning process, to study that black box that exists between the teacher and the student (Fig. 2B); in the first place, it is required to adapt teaching strategies such as Challenge-Based (CBL), Project-Based (PBL), Problem-Based (PrBL) or in general Active (AL) Learning to the reality dictated by the social situation. For example, if society needs to develop a project, product, or solution, teachers must adapt the technique to propose solution strategies. Today the methodology is very flexible, whether teaching is face-to-face, distance, or hybrid formats (Fig. 2B). Finally, the evaluation techniques and instruments must be adapted with a parallel development of the devices that can be used for this purpose. Today, job skills have changed, and employers move at the pace of society, so human resources offices look to the evolution of society to demand skills from university graduates that give them greater competitiveness. For this reason, a research group in all these processes is necessary due to the dynamics of the transformation of education and society.

B. Paradigm shifts in education

This interdisciplinary research line works in a theoretical framework to help faculty members adapt their core concepts and practices in their education discipline focused on student learning. The COVID-19 pandemic and the resulting global recession have transformed the global jobs and skills landscape. These changes have accelerated the need to reskill, upskill, learn, and redeploy at scale: 50% of all employees will need to be retrained by 2025, and 40% of the core skills of today's workers are expected to change in the next five years [21]. This situation indirectly affects the Higher Education Institutions (HEI) that must adapt and update the study plans of the different academic programs to collaborate creating stronger labor markets by training more prepared professionals [22].

The group of experts working on this line of research is currently developing a global skills taxonomy to establish a common language suitable for more efficient collaboration between educational institutions, employers, and governments to reskill, upskill, learn, and redeploy STEM talent. The most successful approaches will consider shifting demographics and changing job roles, and harness disruption as a means of designing academic programs that meet the needs of Industry 4.0. This proposed global skills taxonomy consists of:

1. *Definitions.* A set of definitions and differentiation of commonly used terms. Establishing a common set of definitions and differentiations of terms used to describe skills is a critical first step in building a global skills taxonomy. The goal is to provide a framework for categorizing specific skills, knowledge, attitudes, and abilities. The proposed definitions of key terms are based on a comprehensive literature review.
2. *Categorizations.* A categorization of skill clusters with various levels of granularity. Multi-level skill clustering increases the effectiveness and scope of the taxonomy by allowing employers and academia to map their taxonomies onto the global framework. Using qualitative and data-driven methods, skills can be grouped according to similarity. The granularity increases with each level: the first levels remain

constant as the fundamental framework; intermediate levels provides opportunities to flexibly add skills in the face of ongoing and unforeseen transformations (such as the one caused by the COVID-19 crisis); and the higher levels are determined jointly by the end users of the taxonomy: employers and academia.

3. Recommendations. Adoption mechanisms in teaching-learning and assessment practices. The taxonomy must be an "active" document that is continually updated to reflect the changing nature of labor markets typical of the Fourth Industrial Revolution, so access to this information must be agile and open, in order to be considered a genuine global reference. Some examples of recommendations that can be made to the HEI academy, to encourage the adoption of this taxonomy among teachers, are the following:

- Understand current skills gaps, set goals, and communicate to students the importance of developing skills according to a global taxonomy [23].
- Incorporate change by adopting new skills-based teaching practices, allowing students to become aware of and engage in their own skills-based learning processes [24].
- Incorporate skills-based practices into all of your courses, and also encourage course design in the Collaborative Online International Learning (COIL) modality, to raise global awareness of the benefits of aligning around a common taxonomy [25], [26].

4. Study cases. Creation of a repository of examples of how taxonomy can be used to lead planetary education in the Education 4.0 Framework. The taxonomy can be leveraged to forecast skills trends at global, national, and industry levels through qualitative and data-driven efforts. HEIs can take advantage of the taxonomy to align with the top emerging skills in demand by the industry. Due to future uncertainty, this repository has the peculiarity that it is not static, but can be modified and fed with new case studies.

C. Urban Science

Urban science is an interdisciplinary field that studies cities, their behavior in terms of how they grow and develop, including the problems they face on the process. Urban science involves various disciplines, for instance: architecture, civil engineering, urban engineering, economics, sociology, politics, transportation, environmental engineering, landscape engineering, energy, among others. Urban science becomes relevant with the growth of urban cities and rapid population growth around the globe. Understanding a city, through data and statistics, enables predicting future trends and challenges with the aim of defining well thought strategies to mitigate these challenges. This research line creates the needed places where people live and work with an emphasis in a sustainable environment and comfort and participate in decisions through citizen science.

Faculty within SOI-STEM has done research on urban information systems to analyze urban change with a close collaboration with the local governments and industry. In these collaborations, through meetings and surveys, stakeholders assert their needs, which can be covered from educational interventions in the form of a challenge. In this way the problem is resolved, and students acquire knowledge and skills. To date, this research has focused on Monterrey and Veracruz cities. Efforts have been led to define the economic cost of urban sprawl in Monterrey, to create an urban information system for Monterrey, and to elaborate the urban plan for the city of Veracruz [13].

Our university is currently working on a national effort toward Electromobility. Professors from the School of Engineering of different campuses have been working on defining the critical route that a city must follow in order to transform its transportation systems to adopt electric vehicles and define a methodology and framework for smart mobility towards 2030 [27]. In this context, electric vehicles include cars, buses, and scooters and bicycles (private, public, and personal mobility). The research includes different dimensions for a diagnostic of the current situation in terms of technology; society and culture; urban spaces and infrastructure; and economy, normativity, and politics. The framework encompasses a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis that the involved stakeholders must consider for the journey towards electromobility.

A key part of the electromobility effort at our university is the Electrobus project. This project aims to design and build an electric bus from scratch with the collaboration of industry, professors, and engineering students from a variety of engineering programs. Several companies are donating hardware, software, and know-how for the Electrobus. Faculty and students are contributing with their knowledge and design work to generate a detailed engineering design of the bus, incorporating innovative features according to the final users' needs and stakeholders' requirements. The bus is expected to be on route by 2023.

D. Data Science in Education

This interdisciplinary research line integrates computer science and statistics with education and social science. This research line analyzes useful knowledge not only to inform policy and practice, but also, to help students to have a more meaningful learning experience. As the process of data management can be sometimes difficult, the process is first to identify existing resources and the results obtained, and second, to identify the data resources that do not exist and the phases of how to generate that data.

Universities have years of experience educating and shaping the new professionals. There are huge amounts of information in terms of grades, performance in certain courses according to their profile, backgrounds, program selection, and more. As professors, we might have our theories of certain behaviors that help students to enhance their learning experience and success in a particular academic area. We might also have identified other behaviors that put in risk students' performance and possibilities of success in their studies. Data science enables the analysis and visualization of this data to understand relevant correlations to predict specific results [28], [29].

Our interdisciplinary research group looks forward to analyzing data in an educational context to find patterns and draw insights to understand the performance of an individual and a collective level. Data Science can integrate different systems, platforms and databases and use the analyzed information to make decisions in admissions programs, academic performance, faculty effectiveness and wellness, university outreach, etc. This knowledge can empower educators to define data-driven policies and strategies for the continuous improvement of educational institutions.

E. Diversity, Equity and Inclusion (DEI)

DEI is an interdisciplinary research line that promotes awareness of the presence of individual differences, justice, impartiality and equity, and environments in which everyone feels welcome. It is well known that diverse groups integrate different perspectives and allow having a bigger and more complete picture of contexts and situations, which translates in the possibility of making informed decisions for better business strategies. However, in practice, it is not that easy to have diverse groups and have efficient communication and collaboration. Depending on our own cultural backgrounds, our mental models create unconscious bias on the way we think, communicate, and act regarding certain roles in society. These mental models affect our decisions and translate on behaviors that limit the possibility of having equal opportunities for all.

Until now, a great part of our research in DEI has focused on women in STEM, including high-school students, undergraduate students, and professionals. However, the scope of our group looks forward to investigating other minorities, for instance people with disabilities, of different races and cultures, indigenous people, illegal migrants, marginalized communities, and LGBTQ (lesbian, gay, bisexual, transgender, and questioning or queer). Throughout the world, there is a disparity between those who do not have access to technology by location or by poverty; these are also included in this group.

Historically, women have been minorities in the workplace, especially in leadership roles. In recent years, several efforts have been implemented to promote women professional development and equal opportunities to have more diverse and inclusive teams. Even though some milestones have been achieved, there is still much work left to do in this cultural change journey. When we focus on STEM, the gender gap is bigger. Women's underrepresentation in STEM careers is influenced by gender stereotypes and bias. Gender stereotypes and not having women role models affect girls' interest in STEM from an early age. From those women who do choose a STEM program and get a degree, there are some that do not join the workforce or that decide to pursue non-STEM jobs, or that leave the workforce once they become mothers. There are multiple reasons behind these decisions that impact the gender gap in the workplace.

Researchers from SOI-STEM have conducted several efforts to promote the participation, empowerment, and development of women in STEM. The project “Building the future of Latin America: engaging women into STEM (W-STEM)” received an Erasmus grant to address gender issues in STEM, collaborating with different universities in Latin America [30]. The School of Engineering at our university implemented a national initiative called Women in Engineering and Science to foster the participation of women in STEM areas; this initiative has implemented several efforts in terms of mentoring programs for high school and engineering students, dissemination, linkage with other universities and companies, and coaching female researchers in STEM areas [31]. A particular effort in peer mentoring is the project of Lean In Circles, peer-mentoring between women faculty at our Engineering School across the country. Professors share their experience of being part of this valuable group, what they have learned, and the impact it has had in their professional live [14].

Finally, because of the economic, political, and social problem, those who are migrating through Mexico to reach another country, perhaps illegally and without documents, are included in these cases. By identifying these and other mentioned unprivileged groups, the research team intends to collaborate with the government and other entities by developing studies that answer research questions about what educational strategies in SOI-STEM can improve equality in access to knowledge. The end goal is to understand how these strategies improve the living conditions of society in general.

IV. Discussion

The main objective of SOI-STEM research group is to foster a socially oriented interdisciplinary vision in STEM education to meet the challenges of the 21st century through interdisciplinary education that promotes diversity, equity, and inclusion. In our rapidly changing world, people must be prepared to adapt to new contexts and keep learning. When we think about what the top skills are that a professional must have, usually the responses that come to our mind are leadership, creativity, teamwork, and communication [32], [33]. Table 1 shows the 15 top skills reported for 2025 by the World Economic Forum [5] and the 15 top skills in 2019 indicated by the QS Global Skills Gap Report [34].

TABLE I. Top Skills

	Top Skills	
	Top 15 skills for 2025	***Top skills in 2019***
	World Economic Forum [5]	***QS global skills gap report [18]***
1	Analytical thinking and innovation	Problem solving
2	Active learning and learning strategies	Communication
3	Complex problem-solving	Teamwork
4	Critical thinking and analysis	Flexibility / adaptability
5	Creativity, originality, and initiative	Interpersonal skills
6	Leadership and social influence	Data skills
7	Technology use, monitoring, and control	Resilience
8	Technology design and programming	Organizational skills
9	Resilience, stress tolerance and flexibility	Creativity
10	Reasoning, problem-solving and ideation	Subject knowledge
11	Emotional intelligence	Technical skills
12	Troubleshooting and user experience	Leadership
13	Service orientation	Language skills
14	Systems analysis and evaluation	Negotiating skills
15	Persuasion and negotiation	Commercial awareness

Besides technical and interpersonal skills, it can be observed that it becomes more relevant to develop complex problem-solving, analytical thinking and innovation, and active learning. Formal education systems should be shaped to develop these skills on students. At Tec de Monterrey, through the Tec21 Model, students are evaluated through the acquisition of competencies that encompass these skills, through collegiate rubrics. Education has a vital role to play in developing competencies, knowledge and skills that enable

people to contribute and benefit from a sustainable and inclusive environment [21], [35]. It is essential to learn to define clear and relevant goals, to collaborate in diverse groups integrating different perspectives, and propose multiple solutions to the big and complex challenges that affect us all. Education must do more than preparing young professionals for the workforce; it must equip people with the competencies and skills they need to become responsible and engaged citizens committed to contribute to the sustainable development of their world. The fourth industrial revolution does not have to create the type of inequality produced by the first [36]. Globalization and technology development are transforming our world and the challenge is to create a better future for all; to fight inequality, poverty, hunger, disease, and unemployment.

Since 2021, our research group has had important results through the presented SOI-STEM framework. Professors have carried out educational interventions in their classes and student groups, impacting more than 12 thousand students through the Tec21 educational model. These results have been disseminated in international conferences and high-impact scientific publications, in those that collect, in many cases, the experiences and comments of the students (https://tec.mx/en/soi-stem). In addition, as a process of continuous improvement, institutional instruments have been used, such as student satisfaction surveys, in which it has been observed that the strategy followed in the proposed framework generates better results: increment in learning gain, in the engagement and the skills acquired.

V. Conclusions and Future Work

This paper describes the work carried out for the formation of a multidisciplinary team of professors in STEM with a view to directing efforts towards a socially oriented education. As a result, the framework that encompasses the work carried out by the focus group through educational interventions is described. The ultimate goal of this group is to develop skills in students, on the way to a more sustainable future. The active and experiential strategy of challenge-based learning is used, in which students obtain knowledge and develop skills while solving real challenges. In this sense, external stakeholders, mostly small and medium-sized local companies, and government, allow faculty and students to solve part of their daily problems. In this way, a new generation of professionals is generated who meet the requirements of industry 4.0. Within the future work planned for the team are collaboration projects with international partnerships and external organizations. The interdisciplinarity of our group has shown us the potential of diversity. We are convinced that working together towards the same goal, we can positively impact through education the development and well-being of our society. The SOI-STEM group is, however, quite young and there is still much work to do for a regional, national, and international outreach.

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References

[1] M. Heras and I. Ruiz-Mallén, "Responsible research and innovation indicators for science education assessment: how to measure the impact?," *International Journal of Science Education*, vol. 39, no. 18, pp. 2482–2507, Dec. 2017, doi: 10.1080/09500693.2017.1392643.

[2] S. M. James and S. R. Singer, "From the NSF: The National Science Foundation's Investments in Broadening Participation in Science, Technology, Engineering, and Mathematics Education through Research and Capacity Building," *CBE Life Sci Educ*, vol. 15, no. 3, p. fe7, Fall 2016, doi: 10.1187/cbe.16-01-0059.

[3] A. Struyf, H. De Loof, J. Boeve-de Pauw, and P. Van Petegem, "Students' engagement in different STEM learning environments: integrated STEM education as promising practice?," *International Journal of Science Education*, vol. 41, pp. 1387–1407, Jul. 2019, doi: 10.1080/09500693.2019.1607983.

[4] J. Kareem, R. S. Thomas, and V. S. Nandini, "A Conceptual Model of Teaching Efficacy and Beliefs, Teaching Outcome Expectancy, Student Technology Use, Student Engagement, and 21st-Century Learning Attitudes: A STEM Education Study," *INTERDISCIP J ENV SCI ED*, vol. 18, no. 4, p. e2282, Apr. 2022, doi: 10.21601/ijese/12025.

[5] A. Fiszbein, C. Cosentino, and B. Cumsille, "The Skills Development Challenge in Latin America: Diagnosing the Problems and Identifying Public Policy Solutions," p. 76.

[6] UNESCO, "Engineering for Sustainable Development: Delivering on the Sustainable Development Goals," *UNESCO*, 2022. https://en.unesco.org/reports/engineering (accessed Feb. 13, 2022).

[7] P. Caratozzolo, A. Alvarez-Delgado, and S. Hosseini, "Creativity in Criticality: tools for Generation Z students in STEM," in *2021 IEEE Global Engineering Education Conference (EDUCON)*, Porto, Portugal, Apr. 2021, pp. 591–598. doi: 10.1109/EDUCON46332.2021.9454110.

[8] A. Neaman, S. Otto, and E. Vinokur, "Toward an Integrated Approach to Environmental and Prosocial Education," *Sustainability*, vol. 10, no. 3, Art. no. 3, Mar. 2018, doi: 10.3390/su10030583.

[9] K. Howells, "Future of Education and Skills 2030," 2018. https://www.oecd.org/education/2030-project/ (accessed Feb. 13, 2022).

[10] V. Silber-Varod, Y. Eshet-Alkalai, and N. Geri, "Tracing research trends of 21st-century learning skills," *British Journal of Educational Technology*, vol. 50, no. 6, pp. 3099–3118, 2019, doi: 10.1111/bjet.12753.

[11] P. Caratozzolo, A. Alvarez-Delgado, Z. Gonzalez-Pineda, G. Sirkis, and C. Piloto, "Fostering Soft Skills in Engineering in the Education 4.0 Framework," in *Proceedings of the LACCEI international Multi-conference for Engineering, Education and Technology*, Buenos Aires, Argentina, 2021, vol. 2021-July. doi: 10.18687/LACCEI2021.1.1.195.

[12] Y. Eshet-Alkalai, "Thinking in the Digital Era: A Revised Model for Digital Literacy," *Issues in Informing*

Science and Information Technology, vol. 9, pp. 267–276, Feb. 2022.

[13] A. Carpio, R. Ponce-Lopez, and D. F. Lozano-García, "Urban form, land use, and cover change and their impact on carbon emissions in the Monterrey Metropolitan area, Mexico," *Urban Climate*, vol. 39, p. 100947, Sep. 2021, doi: 10.1016/j.uclim.2021.100947.

[14] V. Lara-Prieto *et al.*, "Women Engineers Empowerment through Linked Experiences," in *2021 IEEE Global Engineering Education Conference (EDUCON)*, Porto, Portugal, Apr. 2021, pp. 289–293. doi: 10.1109/EDUCON46332.2021.9454115.

[15] P. Caratozzolo, A. Alvarez-Delgado, and S. Hosseini, "Metacognitive Awareness and Creative Thinking: the capacity to cope with uncertainty in engineering," in *2020 IEEE Global Engineering Education Conference (EDUCON)*, Porto, Portugal, Apr. 2020, pp. 638–643. doi: 10.1109/EDUCON45650.2020.9125135.

[16] P. Caratozzolo, A. Alvarez-Delgado, and S. Hosseini, "Improving Creative Thinking in Engineering Students Through Art Appreciation," presented at the 2019 ASEE Annual Conference & Exposition (ASEE), Tampa, FL, USA, Jun. 2019. doi: 10.18260/1-2--32947.

[17] P. Caratozzolo, S. Rosas-Melendez, and C. Ortiz-Alvarado, "Active Learning Approaches for Sustainable Energy Engineering Education," in *2021 IEEE Green Technologies Conference (GreenTech)*, Denver, CO, USA, Apr. 2021, pp. 251–258. doi: 10.1109/GreenTech48523.2021.00048.

[18] Q. Iqbal and K. Piwowar-Sulej, "Sustainable leadership in higher education institutions: social innovation as a mechanism," *International Journal of Sustainability in Higher Education*, vol. 23, no. 8, pp. 1–20, Jan. 2021, doi: 10.1108/IJSHE-04-2021-0162.

[19] P. Caratozzolo and J. Membrillo-Hernández, "Challenge Based Learning Approaches for Education 4.0 in Engineering," in *Proceedings of the 2021 SEFI Conference*, Berlin, Sep. 2021, pp. 110–118.

[20] J. Membrillo-Hernández, R. García-García, and V. Lara-Prieto, "From the Classroom to Home: Experiences on the Sudden Transformation of Face-to-Face Bioengineering Courses to a Flexible Digital Model Due to the 2020 Health Contingency," in *International Conference on Interactive Collaborative Learning*, 2020, pp. 488–494.

[21] World Economic Forum, "The Future of Jobs Report 2020," 2020. https://www.weforum.org/reports/the-future-of-jobs-report-2020/ (accessed Feb. 13, 2022).

[22] World Economic Forum, "Building a Common Language for Skills at Work A Global Taxonomy," 2021. https://www.weforum.org/reports/building-a-common-language-for-skills-at-work-a-global-taxonomy/ (accessed Feb. 13, 2022).

[23] S. McGuinness, "How useful is the concept of skills mismatch?," Apr. 24, 2017. http://www.ilo.org/skills/pubs/WCMS_552798/lang--en/index.htm (accessed Feb. 13, 2022).

[24] C. Chappell, A. Gonczi, and P. Hager, "Competency-based education," in *Understanding adult education and training*, Routledge, 2020, pp. 191–205.

[25] A. B. de Castro, N. Dyba, E. D. Cortez, and G. G. Pe Benito, "Collaborative Online International Learning to Prepare Students for Multicultural Work Environments," *Nurse Educ*, vol. 44, no. 4, pp. E1–E5, Aug. 2019, doi: 10.1097/NNE.0000000000000609.

[26] C. W. Nicholas, "Beyond the Program: A Case Study Evaluating the Learning Transfer of a Collaborative Online Course Development Program," Ed.D., Ann Arbor, United States, 2021. Accessed: Feb. 13, 2022. [Online]. Available: https://www.proquest.com/docview/2572615905/abstract/112C5C0366F04BB4PQ/1

[27] J. G. Lozoya-Reyes *et al.*, "Conscious Mobility for Urban Spaces Application," p. 12, 2021.

[28] J. Rodriguez-Ruiz, A. Alvarez-Delgado, and P. Caratozzolo, "Use of Natural Language Processing (NLP) Tools to Assess Digital Literacy Skills," in *2021 Machine Learning-Driven Digital Technologies for Educational Innovation Workshop*, Dec. 2021, pp. 1–8. doi: 10.1109/IEEECONF53024.2021.9733779.

[29] P. Caratozzolo, J. Rodriguez-Ruiz, and A. Alvarez-Delgado, "Natural Language Processing for Learning Assessment in STEM," in *2022 IEEE Global Engineering Education Conference (EDUCON)*, Mar. 2022, pp. 1549–1554. doi: 10.1109/EDUCON52537.2022.9766717.

[30] F. J. García Peñalvo, A. Bello, A. Dominguez, and R. M. Romero Chacón, "Gender Balance Actions, Policies and Strategies for STEM: Results from a World Café Conversation.," *Education in the knowledge society*, no. 20, pp. 31–1, 2019.

[31] A. K. R. Lappe, D. Torales-Sanchez, A. B. G. Fuentes, and P. Caratozzolo, "Work in Progress: Addressing Barriers for Women in STEM in Mexico," in *2021 IEEE Global Engineering Education Conference (EDUCON)*, Porto, Portugal, Apr. 2021, pp. 1600–1604. doi: 10.1109/EDUCON46332.2021.9453901.

[32] P. Caratozzolo, G. Sirkis, C. Piloto, and M. Correa, "Skills Obsolescence and Education Global Risks in the Fourth Industrial Revolution," in *2020 IFEES World Engineering Education Forum - Global Engineering Deans Council (WEEF-GEDC)*, Cape Town, South Africa, Nov. 2020, pp. 1–5. doi: 10.1109/WEEF-GEDC49885.2020.9293687.

[33] S. Chakrabarti, P. Caratozzolo, B. Norgaard, and E. Sjoer, "Preparing Engineers for Lifelong Learning in the Era of Industry 4.0," in *2021 World Engineering Education Forum/Global Engineering Deans Council (WEEF/GEDC)*, Nov. 2021, pp. 518–523. doi: 10.1109/WEEF/GEDC53299.2021.9657247.

[34] QS, Quacquarelli Symonds, "The Global Skills Gap in the 21st Century," *QS*, 2018. https://www.qs.com/portfolio-items/the-global-skills-gap-in-the-21st-century/ (accessed Feb. 14, 2022).

[35] World Economic Forum, "Challenges and Opportunities in the Post-COVID-19 World," *World Economic Forum*, 2020. https://www.weforum.org/reports/post-covid-19-challenges-and-opportunities/ (accessed Feb. 13, 2022).

[36] J. Sachs, C. Kroll, G. Lafortune, G. Fuller, and F. Woelm, *Sustainable Development Report 2021*. Cambridge University Press, 2021.