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SUSTAINABLE ENGINEERING EDUCATION EMBEDDED CURRICULA RESEARCH PROJECT

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ABSTRACT

A previous conference paper with case study report findings began this research so as to inform and be of use to the International Association for Continuing Engineering Education (IACEE) institutions and its membership on the importance of embedding sustainability in all engineering education courses from the beginning to the end of the Degree and beyond into Continuing Engineering Education (CEE) . This present project continues to qualitatively research and investigate the extent to which and how Engineering Learning Curricula (ELC) incorporate and embed sustainability as central to the future work practice of all engineers. Specifically, as the project takes a more comprehensive and longer-term approach to be of ongoing use to all engineering education faculties and institutions, corporate and government policy development, as well as Continuing Engineering Education (CEE) providers. This research uses the digital platform of Sustainability Education & Research IN Action (SERinA), an IACEE Global Initiative, as a future database reporting on best ELC practices in all forms of Engineering Education and post-CEE practice. IACEE's academic engineering member organisations, member institutions, and other engineering institutions outside of the IACEE will be incorporated in the long term into this research project. Initially, information will be obtained via each institution's external website and its academics for this research project and this report paper. This project will also, in the future, seek to interview graduate engineering students on how effective their degrees were in embedding sustainable learning understandings useful in their post-graduate world of engineering practice.

1 INTRODUCTION

The Brundtland Commission's report defined sustainable development as : *"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (WCED n.d.). This underpins engineering students' need to develop critical thinking approaches to their future work practice and environment, as "Sustainability for the planet is not a sideshow," particularly within everyday engineering practice (la Grange, Smith, and Soeiro 2022). Critical thinking presupposes assent to rigorous standards of excellence and mindful command in engineering practice via effective communication and problem-solving. Currently, the most commonly accepted way of assessing the impact, quality, and reputation of universities and other higher education institutions is the Global Ranking of Universities (GUR). However, concerning the contribution of academic institutions to sustainable development, one of the most important measurements is expected to be the Quacquarelli Symonds (QS) World University Ranking®. Since starting in 2023, this ranking will evaluate two new categories: social impacts and environmental ones (QS 2023). Furthermore, in 2010, the University of Indonesia launched the ambitious UI GreenMetric Project to measure the direct impact generated by sustainability strategies in universities. The UI GreenMetric allows us to know each university's regional and global efforts and the

effects of each sustainability strategy (UI GreenMetric 2022). On the other hand, The Times Higher Education (THE) Impact Rankings assess universities against the UN Sustainable Development Goals (SDGs) in four areas, namely research, stewardship, outreach and teaching. In the fifth year, THE Impact Rankings reached to 1,591 universities from 112 countries/regions in 2023 (THE, 2023).

It is a fact that engineering is about the scientific knowledge and practice of solving problems. So far, it plays a significant role in the survival of humankind and improving the quality of life. Now the most critical problem for humankind is how to ensure sustainable development by preserving our planet. In this context, engineering has a significant role to play and the engineering education should contribute to this new role for realization of sustainability.

Creative problem-solving skills are needed to “evaluate the implications of their solutions beyond their immediate technical context" (la Grange, Smith, and Soeiro 2022). However, critical thinking skills and the ability to collect, evaluate, and utilize information are often not advanced in current engineering graduates. Engineers and engineering programs have played and will continue to play a crucial and pivotal role in assisting the global community in meeting fast-changing needs and the UN Sustainable Development Goals by 2030 (Soeiro, Smith, and Grange 2022). Therefore, sustainability thinking should become ingrained into the engineers` critical thinking of daily practice as a fundamental core value, just as safety has become a universal central tenant of engineering practice. This should begin immediately, from 1st year of learning as a student. To have the best chance of success, sustainability, in all of its emerging facets, must form an integral and critical thinking part of the mind and toolsets of engineers in all aspects of their education, research, and practice. For this to occur, this paper proposes that sustainability must become an essential and integral component of the education and training of engineers across all engineering curricula. Over many decades, there have been worldwide calls for the embeddedness of sustainable thinking and practice to be part of all engineering curricula and not just an add-on. This demands that Critical Sustainability Thinking become ingrained as a fundamental core value.

This all links with the IACEE Porto Declaration, challenging engineers, especially the IACEE’s members, to take this on board and become embedded in everyday practice and learning opportunities: *“In the IACEE World Conference held in May 2016 and under the theme “Innovation in Continuing Professional Development: A Vision of the Future” participants signed a declaration”.* The Porto Declaration then led to the creation of a database of best practices called SERinA (Sustainable Education Research in Action). This ongoing research project intends to post the findings and further research to be accessed within the SERinA website databases (International Association for Continuing Engineering Education n.d.).

2 RESEARCH AIM

The main research aim is to qualitatively research and investigate the extent to which and how Engineering Learning Curricula (ELC) incorporate and embed

sustainability as central to the work of all engineers, be it in planning, practice, or policy, within both the private and public sectors. In the long term, it is intended to investigate via interviews with past students and now working engineers whether what they learned concerning sustainability at university is helpful in their everyday practice.

3 METHODOLOGY

This work in progress is part of a study that aims to determine via case studies, examples, and scenarios, allowing knowing and interpreting the positioning of educational institutions in the sustainability ecosystem. The research aims to provide descriptive information and enable a deeper understanding of global sustainability strategies. In addition, it analyses the actions and programs that different institutions are carrying out concerning sustainability.

4 RESULTS

Below are two case studies shared by academics involved in delivering each program and further examples of competence frameworks.

4.1 State University of New York – University at Buffalo (SUNY - Buffalo)

Sustainability efforts in practice are inherently broad. In a sense, this makes teaching challenging, for example, in an MS degree program, as postgraduate degrees are typically expected to add depth to a student's previously acquired knowledge base. At the State University of New York – University at Buffalo (University at Buffalo 2023), a 30-credit MS degree program has been created that provides the breadth and depth needed to satisfy the far-reaching diversity of sustainability content and the expectations for going deep into the content. This paper offers the program as a case study, including outcomes on admitted students and post-graduation career paths. SUNY-Buffalo is consistently ranked as one of the top global Universities for sustainability. The 2021 Times Higher Education Impact rankings associated with the United Nations Sustainable Development Goals listed the campus as #1 in the world for Climate Action and #2 for Affordable and Clean Energy. There is a culture of sustainability on and off campus, including faculty research, educational programming, and degree opportunities.

Recognizing that sustainability content is not "owned" by any single discipline, the degree is held within SUNY-Buffalo's School of Engineering and Applied Sciences. This facilitates the interdisciplinary training required to cover the breadth of topics needed – housing within a single department would tie students to introductory courses from that one program. Further, the degree allows students to take 20% of their credits (or even 30% with written approval) from outside the School of Engineering and Applied Sciences, adding even more flexibility. Sustainability conversations are most productive when they involve folks with different experiences and viewpoints. Again, this is counter to a typical MS program, where courses often have undergraduate-linked prerequisite training. To address this, along with the fact that many students crave sustainability content, the program casts a wide net in terms of recruitment and admittances. Not all students have an engineering BS degree and those that do come from Civil, Environmental, Mechanical, Aerospace, Chemical, Industrial, and Electrical Engineering backgrounds. Students without formal engineering BS training are expected to prove quantitative competence in

their application. It is typical for the program's Director of Graduate Studies to discuss their case individually to ensure they will succeed in engineering courses. With that said, the program has admitted students with backgrounds in Mathematics, Chemistry, Biology, Environmental Geoscience, Accounting, Environmental Studies, and others. Breadth is provided through required courses. All students entering the program must take at least one Energy, Ethics, and Economics class. Specifically, when creating the program, new courses titled "Ethics of Engineering Sustainability" and "Economics of Engineering Sustainability" were designed to provide this critical content. These courses have students reading, thinking, discussing, and writing. They are not necessarily equation-based, pushing some engineers outside their math-centric comfort zones. They are taught by professors with unique training (e.g., philosophy, environmental economics, social justice, etc.) linked to their education, their research interests, or both. Depth is provided through elective courses and experiential learning. After required classes, students choose seven electives to fill out their degrees. They are encouraged to select these courses thematically, around broad topics such as Climate, Pollution, or Energy. A student focusing on Energy might, for example, choose classes such as Microgrids, Petroleum Engineering, Energy & Environment, and more – courses primarily housing in chemical and electrical engineering. A student focusing on Pollution will likely take environmental engineering courses, including Waste Management, Brownfield Remediation, Green Infrastructure, and Fate & Transport of Pollutants. Elective courses outside the School of Engineering and Applied Sciences are broad but have included popular classes from Urban and Regional Planning, Geography, Geology, Communications, and Operations and Logistics. Courses such as Geographical Information Systems and Industrial Ecology are recommended but not required for all students participating in the program. Significantly, every year the catalog of new classes grows – it is clear that students, including those from more traditional engineering MS programs, seek this sustainability content. Students are strongly encouraged to participate in experiential learning opportunities. Three credits (e.g., one class) are available for students completing a relevant internship experience, which the University/School/Faculty are happy to help them find. As a Research I institution, many students complete MS projects, providing 3 of their required credits. A study abroad opportunity is even available.

On average, the time to graduation has been between nine months and two years, with most students completing in 1-1.5 years. It is possible to complete the degree in two traditional semesters (i.e., nine months), although five graduate classes per semester can be daunting. Participation in research or mid-semester (as opposed to summer) internships will certainly slow time to graduation; those students will likely require at least three traditional semesters, often four. While it has not been quantified, student satisfaction with the program is high, and students have successfully launched (or continued) their careers post-MS degree. Graduates are entering into diverse fields, including regulatory (federal, state, and local levels), health & safety, consulting, industrial, waste management, water treatment, packaging, and more.

The logistics of a proper sustainability-focused graduate degree are challenging because such programming must be interdisciplinary, including many departments and faculty. These challenges are a requirement to make an adequate sustainability

degree. That is to say, while there are many examples, it is challenging to “rebrand” an existing degree within a single department or program to all-the-sudden include sustainability. Far-reaching content not available in any one department is necessary. This can create ownership issues at a University (e.g., “Who gets the tuition revenue?”) and must be considered before initiation. At SUNY-Buffalo, degree ownership by the School instead of a Department made the program launch smoother, but issues with class registration/wait lists, sabbaticals, canceled classes, etc., remain. Finally, cohort development is challenging with students taking courses from many departments. Providing students with a home base is essential, possibly including invitations to departmental seminars and social events, faculty advisors, and more. This conflicts with the broad courses but helps create a more comfortable environment where they can build connections and friendships throughout the program.

4.2 Tecnologico de Monterrey

Regarding this institution, the document "Sustainability and Climate Change Plan 2025" and the results were consulted two years after its implementation (Tecnologico de Monterrey 2023b). According to UI GreenMetric, in 2022, Tecnológico de Monterrey was ranked 232nd, with the participation of 1,050 universities. Its highest score was in sustainability education and research, and its lowest was in water management. At the regional level, Tecnológico de Monterrey ranks 29th in Latin America and 11th in Mexico (UI GreenMetric 2022). Considering 2022 THE Impact Ranking, Tecnologico de Monterrey ranks between 100 and 200 with the participation of 1,410 universities; this position has been held for the past three years. The SDGs that have been best evaluated for Tecnologico de Monterrey are SDG5 (gender equality), SDG6 (clean water and sanitation), SDG11 (sustainable cities and communities), and SDG12 (responsible production and consumption) (Times Higher Education (THE) 2021).

Master in engineering management. There is growing interest in engineering to direct, identify, and effectively implement projects, considering legal and ethical principles, leadership, innovation, and sustainable development. This is further seen in large and multinational companies that also require engineers trained to be leaders of projects, with a mix of deep technical knowledge and soft skills. To meet these needs, the master’s in engineering management seeks to develop an engineer’s communication skills, leadership, and project management, combined with technical and analytical skills specialization to improve their work areas. The Master of Engineering Management is presented as an option, among other industry-oriented programs in Tecnologico de Monterrey, which focuses on different areas of engineering, with the primary objective to develop leaders and project managers, specialists in their area of expertise. This postgraduate program is designed for graduates with bachelor’s degrees in engineering and science, in which the goal is that students know and apply technology tools that help them manage and lead projects, responding to particular needs of the industry, thereby supporting the technological and economic development of the country, strengthening further the company-university relation. As part of the program, the student will carry out a project that meets a need or real problem of a company, where they apply and develop the knowledge and skills promoted by the program, which will be a graduation requirement (Tecnologico de Monterrey 2023a) .

4.3 Example of Competence Framework for Sustainable Construction Safety

The International Safety and Health Construction Coordinator Organization (ISHCCO) was founded in 2003 and is developing a qualification framework for occupational Safety and Health Construction Coordinators (SHCC). This framework meets European and national requirements for SHCC, as well as international requirements (ISHCCO 2023). Furthermore, the system developed by ISHCCO should enable benchmarking based on technical standards, on international and national criteria. For these reasons, the decision was made to deduce quality criteria from the European legislation and respective national implementations and support these with already established professional and international standards of the European Qualification Framework (EQF). The EQF is divided into three criteria for knowledge, skills, and attitudes regarding individual qualifications. In this detailed work, the existing and accepted standards from SHCC professionals were examined and compared with the contents of the European Directive 92/57 by institutions, companies, and educational and training organizations in Europe and the rest of the world. Furthermore, considering changes by UNSDGs to the construction sector, ISHCCO prepared a proposal to adapt the current IQF to include sustainability concerns about Ethics, Work, and Health. The main topics of the proposal address SDGs: 3: Good Health and Well-being; 4: Quality Education; 8: Decent Work and Economic Growth; 9: Industry, Innovation, and Infrastructure;
11: Sustainable Cities and Communities; 12: Responsible Consumption and Production; 16: Peace and Justice Strong Institutions; and 17: Partnerships to achieve the Goal. The adaptation of competencies reflects the needs of SHCC to acquire the knowledge, skills, and attitudes necessary to contribute towards the development of the goals effectively. The proposal also includes the recent implications provoked by the European Union - JRC "Green Comp Sustainability Competence Framework" publication. Finally, the proposal consists of suggestions on how these adapted competencies can be acquired by active SHCC and by future professionals in terms of training and education (Soeiro 2017).

4.4 GreenComp: The European Sustainability Competence Framework

Developing a European sustainability competence framework is one of the policy actions set out in the European Green Deal as a catalyst to promote learning on environmental sustainability in the European Union. GreenComp identifies a set of sustainability competencies to feed into education programs to help learners develop knowledge, skills, and attitudes that promote ways to think, plan, and act with empathy, responsibility, and care for our planet and public health. This work began with a literature review and drew on several consultations with experts and stakeholders working in sustainability education and lifelong learning. The results presented in this report form a framework for learning about environmental sustainability that can be applied in any context. In addition, the report shares working definitions of sustainability and learning for environmental sustainability that form the basis for the framework to build consensus and bridge the
gap between experts and other stakeholders. GreenComp comprises four interrelated competence areas: embodying sustainability values; embracing complexity in sustainability; envisioning sustainable futures; and acting for sustainability. Each area consists of three competencies that are interlinked and

equally important. GreenComp is designed to be a non-prescriptive reference for learning schemes fostering sustainability as a competence (Bianchi, Pisiotis, and Cabrera 2022).

4.5. Engineer Girls of Turkey (EGT) Project

Many statistics show that women are in minority in the field of science and engineering globally. According to the UNESCO Science Report 2021, women represent 33% of researchers, while only 28% of tertiary graduates are in engineering. Furthermore, women remain a minority in technical and leadership positions in technology companies (UNESCO, 2021). Nevertheless, recruiting and retaining a more diverse engineering workforce is utmost important to achieve UN SDGs and to ensure global gender equality.

In order to support the wider representation of women in the field of engineering professionally, Limak Foundation launched their flagship project, **Engineer Girls of Turkey** (EGT), in 2015 with the partnership of the Turkish Ministry of Family and Social Services, Turkish Ministry of Education and United Nations Development Program (UNDP) Turkey Office. The EGT Project consists of three programs for high schoolers, university students and corporate people.

The University Programme involves support for female students of engineering in computer, environmental, electrical-electronic, industrial, civil, chemical and mechanical engineering departments in Turkish universities. The university program includes scholarship and mentoring (by volunteer female professionals of engineering),besides the training program designed to promote their professional and soft skills and online English training. Additionally internship and employment opportunities at different companies are available.

Bogazici University Lifelong Learning Centre contributed to the development of the curricula and deliverance of courses. The curricula give a critical thinking and sustainability approach to the EGT fellows. The program also requires fellows to design and/or attend volunteering activities as a compulsory component of the program. Since the beginning, 710 female engineering students have benefited from the EGT University Program in 7 years (Limak, 2023). The program also extends its borders to Kuwait and Kuwait's Engineer Girls project was initiated.

5 SUMMARY AND FUTURE DIRECTIONS

This study is part of broader research on integrating sustainability competencies, corporate social responsibility, and professional ethics in engineering degrees. Case study research included analysing teaching interventions over several years and a reflection process to provide proposals from different perspectives: curriculum, teaching practice, and institutional support. Civil engineers have a responsibility, as stewards of the built environment specific to civil infrastructure systems on which

society relies, to ensure a sustainable future. Therefore, it is incumbent on engineers to provide a holistic approach to the management of infrastructure throughout its full life cycle participating in multi-disciplinary teams of professionals, including ecologists, economists, and sociologists, that effectively address the issues and challenges of sustainable development (Perks 2007). As seen in this paper, the engineering education community is now at a critical juncture. There has been a significant level of *grassroots* activities but little embedded sustainability structure or organisation within curricula design over the years since the inception of the UN Sustainable Education for meeting the goals in 1997.

The next step will be for university-level engineering schools to think more critically about what should or should not be included in a curriculum into which sustainable engineering has been incorporated and how this should be achieved. The path forward will require the evolution of a set of both tacit and explicit knowledge gain standards, as stated below. As put forward above, the 1997 report of the Joint Conference on Engineering Education and Training for Sustainable Development in Paris called for sustainability to be “integrated into engineering education, at all levels from foundation courses to ongoing projects and research” and for engineering organisations to “adopt accreditation policies that require the integration of sustainability in engineering teaching”. This paper and its research have set out to demonstrate how this responsibility could be ingrained right from the start of learning to become an engineer.

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