ENGINEERING CURRICULA AND THE SDGS: A REVIEW

A. Acitores Suz[1], F. Cruz Mazo[1], S. Moreno Soriano[2], A. Martín Erro[1]

[1]*Universidad Politécnica de Madrid (SPAIN)*
[2]*Universidad Europea de Madrid (SPAIN)*

Abstract

The imperative to swiftly integrate sustainability skills into engineering curricula amidst our current shift in production models catalyzes industries and academic institutions to proficiently equip engineers with the competencies necessary to address the challenges of achieving the Sustainable Development Goals (SDGs). A comprehensive understanding of the prevailing landscape of sustainability skills within universities, alongside discerning the requisites articulated by companies involved in sustainable development, assumes critical importance. Spain has made remarkable strides through pioneering initiatives such as EELISA (European Engineering Learning Innovation and Science Alliance), the ITD (Center for Innovation in Technology for Human Development) led by the UPM, and the European University's School of Sustainability established within the EU.

This article is designed to achieve two primary objectives: firstly, to assess the progress made by Higher Education Institutions in integrating sustainability skills into their curricula and supplementary activities, and second, to identify the training requirements articulated by industries in these domains and their commitment to the SDGs.

Methodology: The study entailed conducting interviews with a diverse cohort of thirty individuals representing various university stakeholders, encompassing directors of degree and master's programs, faculty members, and institutional leaders. Additionally, interviews were conducted with individuals tasked with upholding the quality of engineering education and accreditation. Insights were garnered from managers, HR professionals in relevant companies, deans of colleges and professional associations to capture perspectives from the professional sphere. Tailored questionnaires were meticulously crafted for each group to evaluate institutional progress, faculty engagement, and the specific demands on engineers with sustainable skills. These interviews were conducted in three formats, tailored to the participants' preferences — in person utilizing the Teams platform and, in certain instances, via email to elicit written responses. A comprehensive analysis by target groups was conducted after gathering responses to comprehend the prevailing scenario and draw penetrating conclusions.

While commendable practices championing sustainable education have garnered international acclaim, a dispersal of autonomous teaching initiatives exists, emphasizing the need for a standardized structure across Higher Education Institutions. Tackling this challenge and formulating consolidated, specific models necessitates proactive engagement and resource allocation from the governing bodies of Higher Education Institutions. Embracing a multidisciplinary approach to address real-world challenges can deftly navigate the intricacy and ambiguity often associated with sustainability. It is paramount for students to cultivate an open mindset that contextualizes technical challenges within their social and cultural milieus, laying the groundwork for recognizing the significance and potential of engineering in advancing the SDGs.

Keywords: sustainability competencies, GreenComp, sustainability in engineering, SDGs in engineering, future engineers.

1 INTRODUCTION

Engineering education is rapidly transforming to meet the challenges and demands of the 21st century. Today's engineers face an increasingly complex set of issues, ranging from global sustainability and technological innovation to social and ethical considerations. To address these challenges, higher education institutions (HEIs) are adopting multidisciplinary approaches integrating systems thinking, sustainability, and ethics in engineering education.

Institutions can equip future engineers with the knowledge, skills, and mindsets needed to address the complex challenges proposed in the SDGs. Innovation, new technologies, collaboration, a multidisciplinary approach, and a deep commitment to sustainable development in engineering are necessary tools to achieve this [1]. This is also explained in the Engineering for Sustainable

ISBN: 978-84-09-63010-3

Development report [2]. This report explained the need for a “change of direction” in academia, shifting towards interdisciplinary, student-centered, problem-based teaching. In addition, the report urges institutions to conduct regular reviews of engineer attributes and competencies, proposing a system of professional certifications as a guarantee.

Also, exposure to various disciplines can deepen students’ understanding of the interconnected nature of sustainability issues and the need for integrated solutions [1]. Sharma et al. [3] explained in 2017 that multidisciplinary approaches improve communication skills, time management, and teamwork.

In his book Innovation and Methodology: New Ways of Thinking and Designing (2017) from Kees Dorst [4] states that we can no longer solve our problems. He explains that problems are currently complex (there are many related elements), open (they have no limits), dynamic (they change over time), and interconnected. He adds that these problems, which are difficult to solve, require collaboration as a resolution strategy.

According to the study from Caro Saiz et al. in 2020 [5], another problem raised is excessive specialization in the face of the complex nature of the reality to be studied, taking as an example the socioeconomic and environmental system and their associated problems.

Sustainability is an interdisciplinary term, since it includes three approaches that must coincide: economic, social and environmental. According to the European Commission report of 2021, the most used definition of "sustainable development" is the one that appears in the Brundtland report "Our common future". According to this report, sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The term sustainability incorporates the term time, since a sustainable system, model, solution or development will be one that can be maintained over time without exhausting resources.

The authors of this work are part of the work team of the Engineering Education for a Sustainable Future project, EESF. This project is an international collaboration, funded by the European Union, Erasmus +, in which seven partners participate (Atlantic Technological University (ATU), Universidad Politécnica de Madrid (UPM), Politécnico do Porto (P. Porto), Institut Mines-Télécom Business School (IMTBS), the European E-Learning Institute, Momentum, and Wind Energy Ireland). It is a collaborative work that seeks to improve engineering education, specifically by improving green skills and developing sensitivity in terms of sustainability. The aim is to have engineers better prepared to solve today's complex problems and thus be able to achieve the SDGs.

Engineering's contribution is considered essential to achieving the Sustainable Development Goals of the 20/30 agenda [2], which require the acquisition of sustainable skills, critical thinking, interdisciplinary and international collaboration, continuous learning, equal opportunities (for which the profession and education must be inclusive), the management of technology (referring to the management of metadata and AI), and innovation.

The EESF project aims to collaborate in training future engineers to acquire sustainable skills. To this end, in one of its phases, it was decided to survey each partner country (Portugal, Paris, Ireland, Denmark, and Spain), with 50 surveys divided into three interest groups related to engineering and its education. Each higher education centre should conduct 10 interviews.

The Polytechnic University of Madrid (UPM) has already published the report Sostenibilidad en los estudios oficiales de la UPM 2020 [6], [7], which analysed the implementation of sustainability in the different degrees of the university. We, from the Spanish team of the UPM of the EESF project, coordinated by the ETSIDI Higher Technical School of Engineering and Industrial Design, thought it appropriate to expand the sample to reach 30 consultations to study what has happened in Spain in recent years and thus test the different approaches of the Engineering Schools.

Sustainable Development Goal 4, target 4.7, aims for “all students to acquire the knowledge and skills necessary to promote sustainable development” by 2030.

The Polytechnic University of Madrid is an excellent example of cross-cutting executive action from the Academy with its UPM Environmental Sustainability Plan 2018/19 of the Vice-Rectorate for Quality and Teaching Management. The itdUPM22 is a transversal centre of the UPM, which transfers and promotes the contribution of the Polytechnic University of Madrid to the human development and sustainability agenda and the achievement of the Sustainable Development Goals. Through an interdisciplinary approach, the itdUPM applies innovation to solve problems related to global sustainability challenges. Its building, located in the ETSI Agronomic, Food and Biosystems, received the second prize in the 'Design' category awarded by the World Congress of Green Infrastructure 2016, held in Bogotá (Colombia) in

October of that year. Sustainable Architecture and Urbanism Initiative (http://habitat.aq.upm.es/iau+s/), with an international dimension and interdisciplinary character.

Also at the Spanish level, the Council of Rectors of Spanish Universities (CRUE) has been working for years to introduce Sustainability into the curriculum. In 2005, it published the “Guidelines for the Introduction of Sustainability into the Curriculum”, prepared by the Curricular Sustainability Working Group. It establishes general criteria and recommendations for action in the study plans. The concept of “curricular sustainability” is the process of incorporating sustainability criteria into the teaching and learning of students. The institutional declaration of CRUE [8] - Sustainability was published in the Curricular Sustainability Working Group proposal. Among the general criteria for curricular sustainability in the 2012 report, it is determined as a necessary capacity “Working in multidisciplinary and transdisciplinary teams to provide solutions to the demands imposed by socio-environmental problems derived from unsustainable lifestyles”, including proposals for professional alternatives that contribute to sustainable development. This competence is followed by “Applying a holistic and systemic approach to the resolution of socio-environmental problems and the ability to go beyond the tradition of breaking down reality into unconnected parts”. The latter is undoubtedly linked to the necessary interdisciplinary approach. In April 2023, the CRUE [9] issued the Report on the implementation of Royal Decree 822/2021, on the inclusion of sustainability in university curricula. The Report contains the background to the document published by UNESCO in 2017, “Education for the Sustainable Development Goals. Learning objectives”, which identifies eight key competencies. The Government of Spain, in 2018, with the publication of the “Action Plan for the Implementation of the 2030 Agenda”, committed to ensuring that universities assume the commitment to include sustainability-related competencies, promulgated in Royal Decree 822/2021 [10]. Finally, in January 2022, the European Commission published the “European Commission Sustainability Competence Framework (GreenComp)” [11]

Therefore, we see a commitment from academic institutions and the government to implement sustainable skills in training. But, as we have already mentioned, [2], UNESCO sees it necessary to review the scope of the results.

However, the company is a fundamental part of achieving sustainable development. We cannot ignore our opinion and the real commitment that has been made. For this reason, we see it as essential not only to interview leaders of Higher Education Institutions and engineering professors. It is essential to talk and converse with company executives to find out the requirements required when hiring engineers with sustainability qualifications to solve current problems that are difficult to solve without losing sight of achieving a sustainable future for all.

2 METHODOLOGY

Our research goals were two: First, assess the current state of implementation of Sustainability Development Goals in Engineering Education, regarding how institutions embed these skills in engineering curricula. Second, identify the educational needs required by industry in these domains, and determine their commitment to the SDGs. Yet, we entered this research with no assumptions regarding the status of sustainability goals among engineers.

We investigated these research questions from a qualitative approach. We chose to use qualitative research to describe the creative behavior of design engineers without prior assumptions. We expect to use the results to enumerate guidelines to help adapt curricula for SDGs’ needs.

This research was performed by conducting interviews performed to a group of experts involved in this topic.

The interview questions were related to the required key sustainability skills, how engineering students are now prepared for sustainability, and how engineering directly or indirectly impacts the sustainability agenda.

Several target groups were identified. From the educational institutions, we selected university stakeholders, including directors of degree and master's programs, faculty members, and institutional leaders from the HEI side. From the professional environment, we identified company managers and HR professionals, as well as deans of professional associations.

30 interviews were finally performed, both via online calls and by email. Online Interviews were performed through an online app (Microsoft Teams). Email interviews consisted of sending the participants a questionnaire they had to complete and return to the researchers.

To achieve this, a questionnaire was designed and written using a template that included questions like those in the online interviews. The results of the online calls were transcribed using a template like a form through emails. Finally, a thematic analysis of all the responses was performed.

3 RESULTS

The results of the interviews have been treated concerning anonymity. Once the data obtained from the responses of each interest group were cross-referenced, they were organized into significant themes with a criterion for identifying consensus. The topics identified as the most important and with the greatest consensus are shown below:

3.1 Embedded sustainability in HEIs institutions

At the institutional level, initiatives are being made to raise awareness about the SDGs among students. Students demonstrate a strong commitment to these topics, understanding that their professional future will inevitably be linked to the ability to address global issues such as climate change, inequality, and sustainable resource management.

Sustainability is integrated in two ways. On the one hand, in most degrees, through the Syllabus, selecting the SDGs of the different subjects in the area corresponding to the subject considered. On the other hand, through the behaviour of the institution, in different energy-saving campaigns, waste collection, or the creation of specific actions such as the creation of schools, offices, or sustainability departments, appointing sustainability representatives, etc.

3.1.1 Approaches to embedding sustainability

Students tend to see only environmental sustainability, but they are told that they must design for everyone so that all types of people can use designs, and that is where social sustainability comes in. In general, they are told about sustainability without specifying SDGs. The SDG on which they have a positive impact is specified when they develop projects. Projects are the ideal framework for working in a multidisciplinary way and collaborating with other degrees. There are collaboration experiences with all degrees, journalism, physiotherapy, etc.

3.1.2 Sustainability skills

a) Social Responsibility and Ethical Practices: Instilling a sense of responsibility to society and the ethical implications of engineering decisions.
b) Interdisciplinary Collaboration: Encouraging collaboration across different fields to develop holistic and innovative solutions to sustainability challenges.
c) Problem-Solving and Critical Thinking: Developing the ability to analyse complex sustainability issues and devise effective solutions.

3.1.3 Barriers that affect initiatives in place

The main obstacles to implementing sustainability initiatives in education include inadequate funding and resources, limited awareness and understanding of sustainability issues among educators and administrators, resistance to change within educational institutions, and a need for integration of sustainability principles into existing curricula and educational frameworks.

3.1.4 Measurement of the outcomes and impacts

Sustainability training is measured using different rubrics, both in some ordinary subjects and in the Final Degree Projects. The real impact is difficult to measure, as awareness-raising work bears fruit progressively in the medium term.

3.1.5 Benefits and challenges of a multidisciplinary approach

Advantages - A more holistic view of the engineer, an inherent ability to think about sustainability-based solutions, and a better ability to analyze the design and implement solutions that address future challenges.

Disadvantages or challenges - Time is required to incorporate such disciplinary methods. The time does not exist now because there is no availability to add subjects that emphasize this, as there is a predefined academic structure to which one must align oneself.

3.1.6 Further steps institutions can take

Greater emphasis on social sciences is needed to understand the societal impacts of engineering projects, and courses in environmental policy and ethics are needed to provide a broader context for sustainable practices. Service-learning projects and internships can offer students practical, real-world experience in implementing sustainable solutions, encouraging student-led initiatives, and fostering a culture of sustainability on campus.

3.2 Educational needs on SDG required by the professional environment

At the professional level, responses from heads of companies and professional associations showed that they agree on the importance for engineers to take the sustainability goals as a part of their background.

The integration of sustainability on graduate engineers as well as the rest of engineers must be achieved first, by academia, and second, by the companies themselves to give training. *The latter is important as existing engineers need to acquire additional skills in this area, thus reinforcing the principles and commitments acquired in the educational stage, aligned with the business purpose.*

Heads of companies demonstrated that they are aware in the importance of these topics, knowing the importance for the future to address sustainability matters in the industry.

It is important to say that some of the participants acknowledge some of the demanded skills require longer than the educational stage of engineers and experience is required, as skills required are typically acquired after an extended tenure within companies, usually exceeding four years.

3.2.1 Basic requirements for engineering students

The ideal engineering graduate should have both technical and soft skills. Professionals demand from them to have knowledge of specific technologies leading to sustainable goals (e.g. for decarbonization) and to achieve mindsets that tend to think on innovative solutions embedded with equity, ethical and responsible criteria, having *the ability to apply these principles at all stages of a project's lifecycle.*

They expect to be committed to sustainability principles, respecting ethical principles, and to design innovative solutions with a minimum impact on the environment, promoting social equity and managing natural resources with a responsible criterion.

Professionals with in-depth knowledge of regulations and the ability to interpret rules play a vital role in ensuring organizational compliance and adherence to legal requirements. Their transversal knowledge of the organization allows them to understand how regulations impact different areas, while their strong communication and leadership skills enable them to effectively convey regulatory requirements and lead compliance efforts across the organization.

3.2.2 Sustainability skills

The transversal nature of SDG requires a strong technical background and scientific rigor when generating and presenting reference data with solidity and traceability, but it also requires a high component of soft skills, mainly communication.

Technical skills:

a) Good knowledge of existing and consolidated protocols, methodologies and tools in the academic and business field for the calculation and sizing of attributes related to sustainability. For example, comprehensive life cycle analysis.

b) Protocols for evaluating process efficiency, especially from an energy and material flow point of view.

c) Digitization: Data analysis, AI, generation of metrics and dashboards, Project Management.

Non-technical skills

a) Communicative skills. Knowledge of foreign languages.
b) Teamwork and collaboration.
c) Critical thinking and risk analysis.
d) Management.
e) Analytical thinking, creativity and problem solving.
f) Innovation.
g) Adaptability and resilience in the face of changing and multidisciplinary environments.

3.2.3 How graduate engineers and sustainability skills

Efforts from academia to integrate the sustainability topics in engineering curricula are appreciated. There must be connection between universities and businesses, particularly by providing support to institutions.

3.2.4 Education needs on SDGs for students

Interviewed professionals acknowledged an evolution from academia in the integration of sustainability concepts in the curricula. They perceived that recent engineering graduates have a better understanding of sustainability than in years previously. It is important that educational institutions continue to strengthen their curricula to include aspects related to sustainability in all engineering disciplines. Higher education must incorporate humanistic, transversal, and multidisciplinary training to train tomorrow's talent that is a source of innovation, critical thinking, and social awareness.

3.2.5 Recommendations

In terms of technical competencies, engineering graduates should be familiar with sustainable technologies and practices, such as eco-design, energy efficiency, waste management, water conservation, among others.

3.2.6 Collaboration with HEI

A clear connection between academia and industry is remarked as a key element. Companies must share their needs to HEI in a systematic way, making they know what are the needs from graduates when they face the professional environment. A suggestion made was participating at the teaching level, during the delivery of educational plans for this sensitivity, bringing companies closer to future graduates, thus having a greater presence on students during their still training stage. Another proposal is an efficient increase in hybrid training and scholarship models.

4 CONCLUSIONS

The organization of the interviews and the creation of groups with different sets of questions were very positive. The objective of learning about teaching-learning models, challenges, and results from different perspectives was achieved. A great complementarity in the approaches and a clear desire to promote collaboration between different agents in training activities was revealed, whether in collaboration between the industry and the university or by in inter-centre activities and projects.

Contacting students with problems in real environments and complex situations was valued as very important by everyone. The most valued methodology was project-based learning.

Multidisciplinarity was highly valued, but structural problems of the university were detected that may pose difficulties for its implementation. In particular, the need for longer times and more economic resources was identified to make it feasible.

Social commitment in training activities was one of the pillars for generating significant changes. To achieve this objective, some strategies were proposed, such as incorporating into the training notions of sociology of the environment in which the specific engineering field is developed, for example, sociology of the rural environment for agricultural engineers or sociology of developing countries, to make it easier for engineering students to address social and cooperation aspects.

Critical thinking and systemic thinking are the most important soft skills to develop, along with teamwork and communication skills.

ACKNOWLEDGEMENTS

This research has been performed under

THE ERASMUS + PROGRAMME 2021-2027

Project number: 2023-1-IE02-KA220-HED-000160939

Project name: Engineering Education for a Sustainable Future

REFERENCES

[1] S. Strachan, L. Logan, D. Willison, R. Bain, J. Roberts, I. Mitchell, & R. Yarr, (2021). Reflections on developing a collaborative multi-disciplinary approach to embedding education for sustainable development into higher education curricula. Emerald Open Research, 1(9). Doi:10.1108

[2] *Resumen del informe Ingenierúa para el desarrollo sostenible*. (2021). Organización de las Naciones Unidas para la Educación, la Ciencia y la Cultura. UNESCO

[3] Sharma, B., Steward, B., Ong, S.K., Miguez, F.E.) Evaluation of teaching approach and student learning in a multidisciplinary sustainable engineering course. *Journal of Cleaner Production. D*oi: 10.1016. Vol 142. 2017.

[4] K. Dorst, Innovation and methodology: New ways of thinking and designing. Ed. Experimenta, Theory collection. 2027.

[5] J. Caro Saiz, S. Díaz de la Fuente, V. Ahedo García, D. Zurro Hernández, M. Medalla, J. M. Galán Ordax, L.R. Izquierdo Millán, J. I. Santos Martín, R. del Olmo Martínez, *Libro blanco sobre transdisciplinariedad y nuevas formas de investigación en el Sistema Español de Ciencia y Tecnología*. ISBN 978-84-0 -23333-5, pág. 91-93. 2020.

[6] A. Colmenero, P. Sastre, P. Sánchez-Bayo, *Sostenibilidad en los estudios oficiales de la UPM 2020*. Vicerrectorado de Calidad y Eficiencia, Sostenibilidad UPM. 2021.

[7] UPM, (2018). *Plan de sostenibilidad ambiental de la UPM*. Vicerrectorado de Calidad y Eficiencia. Gerencia y personal docente e investigador.

[8] CRUE, *Directrices para la introducción de la Sostenibilidad en el Curriculum.* Document approved by the Executive Committee of the Environmental Quality and Sustainable Development Working Group of the CRUE, held in Valladolid on 04/18/2005. Document approved by the CRUE General Assembly on 10/27/2005. Review approved in the CADEP Plenary session at the University of Zaragoza on 06/17/2011 and expanded in the CADEP Plenary session on March 9, 2012, in Valencia. Presented at the CRUE General Assembly on June 28, 2012, at the University of Girona. Sustainability_Guidelines_Crue2012 PDF (www.crue.org). 2012.

[9] CRUE, Informe de aplicación del Real Decreto 822/2021. Sobre la inclusión de la sostenibilidad en los planes de estudios universitarios. 2023.

[10] BOE núm. 233, de 29 de septiembre de 2021. Real Decreto 822/2021, de 28 de septiembre, por el que se establece la organización de las enseñanzas universitarias y del procedimiento de aseguramiento de su calidad. pág. 119537 a 119578. 2021.

[11] G. Bianchi, U. Pisiotis. M. Cabrera M., *El marco europeo de competencias sobre sostenibilidad*. Y. Punie and M. Bacigalupo, eds. European Commission. 2022.