

TRANSFORMING ENGINEERING LEARNING TOWARDS SUSTAINABLE DEVELOPMENT

Manel Medhioub, Mohamed Ali Bouakline

ESPRIT School of Engineering, Tunis. Tunisia

ABSTRACT

Sustainable development has emerged as a global priority in response to the challenges posed by environmental degradation, social inequality, and economic instability. Engineering plays a crucial role in addressing these challenges, and engineering education is pivotal in creating a sustainable future. To effectively address these challenges, it is imperative to integrate its principles into the engineering curriculum. The incorporation of the United Nations Sustainable Development Goals (UN SDGs) into specific courses is a commendable start. However, Sustainable Development Goals (SDGs) are not abstract concepts but practical challenges that require real-world solutions. To apply sustainable principles across various engineering contexts, from design and implementation to operation and maintenance, we emphasize the need for a more comprehensive and transformative integration. To adequately prepare engineering students to contribute to the fulfillment of these goals, we propose, in this paper, an approach that aligns with the CDIO framework's principles throughout the engineering learning process. This work is a direct outcome of an initiative at ESPRIT School of Engineering. The teaching and learning process at Esprit is based on active pedagogy and openness to the professional environment, thus fostering the training of operational engineers. We present the process of transforming engineering learning towards sustainable development and identifies key initiatives that have been implemented to achieve this transformation at multiple levels and across diverse disciplines. As a result, a new generation of engineers dedicated to creating a more sustainable world learns how to conceive projects that address environmental, social, and economic issues. The paper explores the benefits of these approaches and the positive impact of these initiatives on student learning outcomes and faculty development.

KEYWORDS

Engineering Learning, Sustainable Development Goals Implementation, Framework, Standards 2,3,7, 9

INTRODUCTION

The structure of society is facing considerable challenges linked to social injustice, environmental degradation, gender inequality, inclusive education, and sustainable development. In this respect, higher education institutions play the role of agents of change from a sustainability perspective and have an obligation to act. They are establishing new cross-sectoral collaborations, securing new sources of funding, and equipping students, faculty, and staff with skills to inspire and empower them to implement sustainable development goals in their daily lives. To design and implement sustainable solutions, future engineers should be equipped with knowledge, skills, and values. Indeed, engineering schools require to incorporate sustainability principles into engineering curricula.

This work discusses a case of Esprit School of engineering. Initially, a new reference framework, considering the specific features of Esprit School of Engineering training, is presented. This framework integrates both the Green Reference Framework and the Conférence des Grandes Ecoles (CGE) Framework, incorporating the latter's five cross-cutting competencies. Then, we propose an approach that integrates SDGs from the learning outcomes to the curriculum and various integrated learning experiences, as well as faculty professional development. The integration of sustainable development objectives has been studied, presenting various aspects of integration, development, and the benefits within this academic context.

This paper is structured as follows. Section 2 reviews related work on the integration sustainability concepts. Section 3 describes the establishment of the ESPRIT reference framework. Section 4 offers insights into the process of transforming engineering learning towards sustainable development. Section 5 highlights the impact of this process on students and faculty members. The last section is devoted to providing a conclusion that encapsulates the details outlined in the paper.

RELATED WORK

Various international initiatives are actively promoting the integration of SDGs within university curricula. This section delves into the approaches employed for incorporating sustainability concepts into engineering education and provides illustrative examples. These initiatives primarily concentrate on enhancing awareness among students and university staff regarding sustainability issues. and cultivate collaborations with businesses and civil society organizations. The engagement of higher education institutions (HEIs) with each Sustainable Development Goal is pivotal for disseminating information and mobilizing individuals through educational strategies and environmentally conscious projects.

For instance, Babes-Bolyai University (BBU) (Zanellato & Tiron-Tudor, 2021), offering study programs in multiple languages, has strategically positioned itself in international rankings related to sustainable development. An investigation was conducted on the official websites of faculties and research centers involved in sustainable development activities. It revealed initiatives such as new educational programs, collaboration with research groups, and articles published on various SDG-related issues. Through its strategic plans and follow-up actions, BBU has achieved an advanced international ranking, showcasing its commitment to reducing ecological footprints and aligning with national, European, and international sustainable development regulations.

Another exemplary model comes from the University of Seville and the University of Extremadura, Badajoz in Spain (Setó-Pamies & Papaoikonomou, 2020), illustrating successful incorporation of ethics, corporate social responsibility, and sustainable development into management education and engineering design departments. Their study emphasizes the concrete perspective management education contributes to SDGs through education, research, innovation, and leadership. Practical implications drawn from stakeholder data include the need for specific training on SDGs for students, contextualized within education for sustainable human development, and the development of cross-cutting skills across the curriculum.

Cheah (2021) presented a comprehensive review of the integration of SDGs in engineering curriculum, particularly in the field of chemical engineering. By placing a stronger emphasis on empowering students, the goal is to equip them for shaping their perspectives on the complex nature of sustainability issues. This involves considering the diverse and sometimes conflicting viewpoints of various stakeholders. An evolving approach in transformative learning centers around sustainability as a discourse.

ESTABLISHMENT OF ESPRIT REFERENCE FRAMEWORK

ESPRIT presentation

The School of Engineering being discussed is a private higher education institution that was founded in 2003. It employs around 400 teachers and has a student population of over 12,000. The four core departments are Civil Engineering, Electromechanical Engineering, Information Technology, and Telecommunications. Many recognitions demonstrate the world-class pedagogy created by the school faculty which empowers students to take on more responsibility in the learning process. The school also provides various academic and non-academic facilities and services to students. To address sustainability challenges and transform engineering learning towards sustainable development, ESPRIT establishes a new reference framework and adopt an approach that integrates SDGs from the learning outcomes to the curriculum and various integrated learning experiences, as well as faculty professional development.

Existing frameworks

The labeling framework, known as the "Sustainable Development and Corporate Social Responsibility Label" (DD&RS), for higher education institutions was introduced in 2015. It is based on a common national set of standards dating back to 2009, in accordance with Article 55 of the Grenelle 1 environmental law. This framework is the result of collaborative efforts involving a dozen universities and Grandes Écoles, the Conference of Grandes Écoles (CGE), the Conference of University Presidents (CPU), the Ministry of Sustainable Development, the Ministry of Higher Education, and the "Réseau des étudiants pour une société écologique et solidaire (RESES)." It allows higher education and research institutions to receive national and international recognition for their sustainable development and corporate social responsibility initiatives. Additionally, it provides institutions with the opportunity to enhance their capabilities within a group of participating establishments by engaging in the labeling committee and auditing candidate institutions.

ESPRIT Framework

The steering committee at ESPRIT has taken the initiative to formulate the ESPRIT SDG Framework by aligning and intersecting two existing frameworks, considering the unique features of our school's training programs. This process involves a meticulous matrix intersection, placing a strong emphasis on aligning sustainable development skills, engineering program objectives, and the SDGs. This strategic approach ensures a systematic and consistent integration of sustainability principles throughout our educational curriculum (UN DESA, 2022).

The Conference of University Presidents framework, which encompasses five axes including Teaching and Research & Innovation, was thoroughly examined and addressed by the committee. Additionally, the second CPU-CGE framework, based on five competencies (foresight, responsibility and ethics, collectivity, change, and systemic), played a significant role in shaping the competency matrix. Notably, the development process underscored the importance of CDIO skills, especially in projects, practical work, and active pedagogy (Porter & Kramer, 2006).

The overarching goal of the Esprit SDG&R Framework is based on the integration of SDGs into education while considering the specificities of our school's curriculum. This framework is structured around two competency families: 'Learning to Apply Knowledge and SDG Skills' and 'Supporting and Recognizing Student Initiatives in SDG Projects.' Following a comprehensive reflection and clarification of competencies and learning situations associated with specific SDGs, each faculty member actively contributed by proposing approaches and suggestions to enhance the integration of sustainability issues into their respective modules/courses. This collaborative effort included considerations for workload and pedagogy details.

PROCESS OF TRANSFORMING ENGINEERING LEARNING TOWARDS SUSTAINABLE DEVELOPMENT

ESPRIT has implemented a series of key initiatives fostering a holistic approach to effectively implement the SDG Framework. The initiatives outlined are categorized into three categories that capture their key objectives and focus areas. They highlight the comprehensive approach taken by ESPRIT, encompassing educational pedagogy, and learning integration, interdisciplinary collaboration and lifelong learning, and experiential learning with a focus on social responsibility. The framework was introduced in September 2022, and since then, it has involved all students, regardless of their specialization.

Category 1: Educational Pedagogy and Learning Integration

Initiative 1: Implementation of Project-Based Learning

The integration of sustainability involves rethinking traditional approaches to teaching and learning, as various skills are delivered through active learning. At ESPRIT, students are constantly engaged in role-playing scenarios, team-based activities, and problem-based learning projects to solve complex problems, often derived from real-life settings. ESPRIT engineering students learn how to analyze and solve complicated and complex problems, along with developing effective collaboration abilities within diverse teams.

Furthermore, PBL stands out as a pedagogical approach especially beneficial within the context of CDIO design-implement courses (Edström & Kolmos, 2012). This Approach provides students with opportunities to apply sustainable development principles during the

design of their projects. Students develop a comprehensive understanding of the social, environmental, and economic implications of their designs. It is also a pedagogical approach that fosters ethical decision-making and critical thinking skills necessary for sustainable engineering practice. To measure sustainability competencies, we have developed appropriate assessment tools and we have established continuous improvement through feedback.

Moreover, Project Fair which is a prominent end-of-year celebration, provides an exceptional platform for students to showcase their work through the organization of exhibition spaces, interact with a diverse audience, and receive feedback in a professional context. Indeed, the focus of Projects Fair edition 2023 was sustainable development and different topics with sustainability awareness were addressed.

Initiative 2: Development of dedicated sustainability-focused courses

Our programs offer dedicated sustainability-focused courses, ensuring that students develop a comprehensive understanding of sustainable development principles. Knowledge and skills necessary to address complex environmental, social, and economic challenges are also taken into consideration. These competencies are deemed essential within the Education for Sustainable Development domain for coping with the increasingly diverse and interconnected world and for contributing to sustainable development (Rosén et al, 2019). As a result, every student in every engineering specialty as shown in Table 1, is given a module providing an initial introduction to sustainable development. This module aims to introduce students to the connections between economic development and the significant environmental issues of today, as well as their social consequences.

Table 1. Dedicated sustainability-focused courses

| Course | Curriculum | Knowledge and competencies |
|---|--|---|
| Sustainable Development | Information Technology and Telecommunication Engineering | Ensure the first immersion of students in sustainable development. Introduce the links between economic development and the major contemporary environmental issues and their social repercussions. |
| Sustainable Development and Social Responsibility Initiatives | Electromechanical Engineering | Familiarize students with the concepts of sustainable development/Social Responsibility, the SDGs and the standards related to Health, Safety and Environment (HSE) as well as their applications in the company. |
| Urban planning and sustainable development project | Civil Engineering | Students imagine, propose solutions and innovate, always respecting the targets of sustainable development. |

Initiative 3: Incorporation of sustainability into core engineering courses

In addition to the presence of dedicated courses, incorporating sustainability into core engineering courses plays a crucial role in ensuring the effectiveness of sustainable

engineering education at ESPRIT. The inclusion of sustainability concepts is ensured across various engineering disciplines. The learning outcomes are following suit, which involve changes to both the content of education and the methods of learning.

Category 2: Interdisciplinary Collaboration and Lifelong Learning

Initiative 4: Promotion of interdisciplinary collaboration

Sustainable development challenges are inherently interdisciplinary and involve collaboration between professionals from diverse fields. To promote interdisciplinary approaches at ESPRIT, we encourage:

- joint research projects: ESPRIT supports faculty and students to engage in collaborative projects that address multifaceted issues and that draw on collective expertise from various disciplines. Additionally, the school seeks to stimulate research on sustainable development.
- interdisciplinary coursework: ESPRIT integrates interdisciplinary elements into its coursework, exposing students to a diverse spectrum of knowledge beyond their core disciplines. These skills are essential for navigating the complexities of real-world challenges.
- innovative initiatives: ESPRIT promotes project-based learning initiatives mirroring real-world scenarios that require collaboration among students with diverse academic backgrounds.

Initiative 5: Promotion of lifelong learning

Skilled engineers are crucial for achieving the 17 Sustainable Development Goals. However, innovative technologies, automation, demographic changes, and employment mobility require continuous reskilling for engineers. A commitment to lifelong learning can ensure that engineers remain well-equipped to contribute effectively to sustainable development. Our courses are regularly updated to reflect advancements in technology and industry trends. In addition, we collaborated with industry partners to ensure that our curricula and integrated projects are aligned with real-world challenges, facilitating practical, lifelong learning experiences. Our commitment to open accessibility and the diversity of online platforms ensures that anyone, anywhere, can benefit from our engineering courses. The variety of our platforms and approaches in the realm of open courses also contributes to lifelong learning in engineering.

Category 3: Practical Experiences and Societal Engagement

Initiative 6: Setup of internships

In the pursuit of aligning engineering education with the principles of sustainable development, ESPRIT establishes four distinct internships. They are designed to provide students with a holistic understanding of the societal and human dimensions of engineering. The goal of the inaugural one "Human and Social Training Internship" is to foster a deep understanding of the human and social aspects of engineering. This internship engages students in activities that promote empathy, cultural awareness, and social responsibility.

In addition, the integration of SDGs into the evaluation of the end-of-studies internship contributes to raising students' awareness and measuring students' understanding of sustainability concepts.

Initiative 7: Fostering club activities

To cultivate a sustainable engineering mindset among students, fostering club activities is also considered an integral component. Our approach to nurturing club activities revolves around three key initiatives. We conducted a workshop to present the seventeen SDGs, Corporate Social Responsibility (CSR), and the significance of universities' contribution to the SDGs. Then, we integrated discussions on CSR emphasizing the role of businesses in creating a positive impact on society and the environment. Finally, we invited professionals and guest lecturers who are industry experts, and they provided practical insights into sustainable engineering practices.

Initiative 8: Training and resources

To align learning outcomes with real-world sustainability challenges, we engaged different stakeholders in engineering education. Partnerships and collaborations between academia, industry, and communities offer ESPRIT opportunities for internships, research projects, hands-on experiences, and cooperative education programs. In addition, the contribution of the industry into curriculum development ensures that graduates possess the skills required by the job market.

We provide advanced technologies like online learning platforms, simulation software, and virtual reality that offer new opportunities to enhance sustainable engineering education. They allow our students to explore and analyze complex systems and scenarios and supplement traditional classroom teaching.

On the other hand, curriculum changes are implemented systematically, with a focus on promoting and developing faculty members. To enhance understanding of sustainability concepts and methodologies, we have established a training program that includes workshops, conferences, and professional development opportunities. This program aims to enable the integration of sustainability principles into teaching practices.

Indeed, to incorporate the SDGs into engineering curricula, a training session was organized to assess the integration of SDGs into the training curriculum and evaluate their extent in the content. Following this, two workshops were conducted to demonstrate concrete methods of incorporating SDGs into the curriculum.

By the conclusion of the first workshop, all participants reached a consensus to include the SDGs in the summer internship and final project forms. Subsequently, by the end of the second workshop, the pertinent SDGs for each unit were identified, with ongoing efforts to integrate additional SDGs.

As an illustrative example, let's consider the implications of integrating SDGs into an English for Engineers course. Here are the proposed learning outcomes aligned with SDGs:

- Demonstrate critical thinking in collaborative environments through debates about the technologies in hand.
- Identify sustainable solutions to Sustainable Development issues and the different co-actors.

- Participate in the elaboration of projects related to social, cultural, and ecological entrepreneurship.
- Propose green innovations through the improvement, mitigation, adaptation, and transformation of existing solutions to sustainable development issues.
- Propose solutions to address issues related to uneven access to technologies.
- Engage with a group to implement permanent solutions to challenges faced in the world and the corporate world in specific.

Over the course of five years, more than 120 pedagogical supervisors have collaborated on nearly 200 units in the ESPRIT training program. The teachers participating in the workshop expressed strong interest in its content, activities, and outcomes, as well as in the training provided. Additionally, they expressed a desire for more time in the workshop, specifically requesting simulations of practical applications and a diverse array of case studies to represent various learning scenarios.

POSITIVE IMPACT OF OUR APPROACH

The positive impact of the sustainable development approach adopted by ESPRIT in engineering education is reflected in its alignment with the CDIO standards (Crawley et al., 2014) and is delved into the tangible benefits on student learning outcomes.

Alignment with CDIO Standards

The process of aligning engineering learning towards sustainable development at ESPRIT is designed to align to specific CDIO standards, namely Standards 2, 3, 7, and 9.

- Standard 2: ESPRIT's commitment to sustainable development is reflected in the learning outcomes of its engineering programs. The implementation of Project-Based Learning at ESPRIT ensures that students develop practical problem-solving skills in addition to theoretical concepts. Through hands-on projects, students are exposed to real-world scenarios where they initiate and design engineering solutions.
- Standard 3: The development of dedicated sustainability-focused courses and the incorporation of sustainability principles into core engineering courses align with CDIO Standard 3. ESPRIT's curriculum design reflects a commitment to providing effective engineering education, seamlessly weaving sustainability concepts throughout various engineering disciplines.
- Standard 7: The promotion of interdisciplinary collaboration and lifelong learning at ESPRIT is a direct manifestation of CDIO Standard 7. By encouraging joint research projects, interdisciplinary coursework, and innovative initiatives, ESPRIT prepares students to operate effectively in the dynamic and multidisciplinary engineering landscape. This aligns with the CDIO framework's focus on producing engineers capable of addressing multifaceted challenges. Furthermore, Internships and club activities at ESPRIT emphasize integrated learning experiences, including interactions with industry, societal engagement, and a deeper understanding of the societal and human dimensions of engineering.
- Standard 9: The improvement of faculty competence, collaborative efforts with industry partners, and a focus on professional development align with CDIO's Standard 9. This

alignment ensures that faculty members are well-equipped to integrate sustainability principles into teaching practices.

Benefits on student learning outcomes

The students have demonstrated a keen interest in sustainable development by incorporating the seventeen SDGs into all club activities. They actively utilize these goals to guide and achieve the objectives outlined in integrated projects. Out of 150 participating teams in project fair, 80 teams actively aligned their projects with the SDGs, showcasing their commitment to addressing global challenges. Among these, 80 projects underwent rigorous evaluation and selection by the DDRS jury. Additionally, 20 teams received visits, culminating in the recognition of the top three teams for their exceptional integration and contributions to the SDGs, as they were awarded prizes for their remarkable achievements.

Furthermore, this approach has yielded numerous benefits for student learning outcomes:

- enhance problem-solving skills and reinforcing academic concepts.
- foster a sense of responsibility and ethical decision-making in engineering practices.
- enhance critical thinking and prepare students for complex real-world challenges.
- ensure students remain relevant and adaptable throughout their careers.
- develop a holistic understanding of societal dimensions and enhance empathy and cultural awareness.
- develop a broader perspective on the role of engineers in addressing global challenges.

These initiatives not only enhance student learning outcomes by providing practical experiences and a comprehensive understanding of sustainability but also contribute to faculty development through engagement in collaborative projects, innovative teaching approaches, and a commitment to continuous learning.

CONCLUSION

Transforming engineering learning towards sustainable development underscores the need for collective action from academia, industry, and stakeholders. The paper outlines a comprehensive and transformative framework adopted by ESPRIT to align engineering education with the principles of sustainable development. A set of initiatives is strategically deployed to effectively operationalize the ESPRIT framework. Informed by the latest findings and best practices in the field, this approach underscores the commitment to empower future engineers with the skills and values needed to contribute effectively to building a more sustainable and equitable future. The positive impact of ESPRIT's approach is evident in its alignment with CDIO standards. The benefits on student learning outcomes, ranging from enhanced problem-solving skills to a broader perspective on global challenges, highlight the success of ESPRIT's initiatives in preparing students for sustainable engineering practice. For continuous improvement, it is imperative to engage additional stakeholders, such as administrative staff, and strive for international certification.

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BIOGRAPHICAL INFORMATION

Manel Medhioub is Faculty member and Chief Academic Officer at ESPRIT School of Engineering, Tunisia. She holds a PhD degree and an Engineering degree in computer sciences. She teaches senior courses related to Network services, cloud computing and security. She has published 7 scientific papers in international journals and conference proceedings.

Mohamed Ali Bouakline is a holder of a Ph.D. in electromechanical engineering and an MBA. His MBA thesis is entitled 'Integration of DDRS Skills in Universities: A Case Study of ESPRIT.' Currently serving as a Senior Teaching Technologist within the pedagogical unit of electronics and electrotechnics, he also holds the position of Head of the Department of Academic Affairs and has previously served as the Head of the Electromechanical Department at Esprit.

Corresponding author

Manel Medhioub
ESPRIT School of Engineering
1, 2 rue André Ampère - 2083 -
Technological Pole - El Ghazala
manel.madhioub@esprit.tn



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