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SPECIAL FOCUS PAPER

Integrating the UN Sustainable Development Goals into Engineering Education: Pedagogical Approaches and Challenges

Alaeddine Boubaker[1] (✉), **Ahmad Shaheen**[2], **Marcellin Yovogan**[3], **Mostafa Mohamad**[4], **Aftab Haider Rizvi**[5], **Anuj Kumar**[6]

[1]European School of Data Science and Technology, Geneva, Switzerland

[2]Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt

[3]Sofia University "St. Kliment Ohridski", Sofia, Bulgaria

[4]College of Interdisciplinary Studies, Zayed University, Abu Dhabi, UAE

[5]Vijay Patil School of Management, DY Patil University, Navi Mumbai, India

[6]Marwadi University, Rajkot, India

ala.boubaker@gmail.com

ABSTRACT

Engineering is central to addressing the world's urgent challenges, from energy and sustainability to access to clean water and safer infrastructure. The UN's Sustainable Development Goals (SDGs) offer a globally accepted blueprint for these, for which the systemic embedding in engineering education is far from uniform. This paper explores pedagogical methods for integrating the SDGs into engineering education and discusses some of the challenges that educators are currently facing. Based on a literature review of worldwide practices, including project-based learning, problem-based learning, and interdisciplinary teamwork strategies for developing the sustainability competence of future engineers, obstacles such as curriculum overload, lack of faculty training, and a limited number of assessment instruments are emphasized. Based on the content taught in their engineering courses, as well as through compulsory climate change education for non-engineers, similar process flows are then considered to determine how they can contribute to addressing the challenges defined in SDG 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

KEYWORDS

Sustainable Development Goals (SDGs), SDG 9 (industry, innovation, and infrastructure), SDG 12 (responsible consumption and production), SDG 13 (climate action), engineering education

1 INTRODUCTION

Technical competence and discipline-specific knowledge have been the major focuses of engineering education. What is clear, however, is that there are increasingly complex global problems such as climate change, energy transition, digital divide, and sustainable infrastructure that demand engineers to think more deeply than ever before in a more traditional problem-based culture but one that again

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serves society. These challenges are very similar to the United Nations' Sustainable Development Goals (SDGs), which are a universal and worldwide framework for peace, prosperity, and environmental sustainability. The integration of the SDGs in engineering education represents a shift away from technical optimization as an exclusive paradigm toward systems thinking, ethical responsibility, and interdisciplinarity. It is also compelling educators to rethink curricula, reconsider what they want students to learn, and figure out how to involve students in tackling actual sustainability problems. This paper examines how educators may facilitate integration through teaching and learning and offers some perspectives on institutional, curricular, and assessment barriers that impact successful implementation.

2 RESEARCH OBJECTIVES

The primary objective of this study is to examine approaches to engineering education for sustainability that better serve UN SDGs, focusing on effective pedagogical methods. The study seeks to:

- Identify teaching frameworks and approaches where the content of engineering education is mapped against SDGs.
- Explore critically the potential contributions of experiential and problem-based learning for engineering students to achieve sustainability capacity.
- Examine the most significant challenges, such as curricular saturation, deficiencies of educators and opposition in institutions to providing SDG education.
- Propose flexible approaches and institutional schemes to integrate SDG-related learning outcomes in engineering education across different fields of study.

3 LITERATURE REVIEW

The integration of the United Nations' SDGs into engineering education has been developed as a cornerstone for international strategies that aim to align higher education institutions with sustainable development. The SDGs' 17 goals target global challenges that are multidimensional, from poverty and hunger (SDGs 1–2) to climate action and partnering for the planet (SDGs 13–17) [1].

A research study by [2] presents a competency-based approach that connects SDG-specific skills (systems thinking, normative judgment, strategic foresight) and pedagogical practices (service learning or interdisciplinary cooperation). Though significant advancements have been achieved, there are some knowledge gaps in literature. However, there are still some open questions for research. A few organizations have reviewed curricula, assessment, and accreditation in the context of the SDGs.

A discipline, such as engineering, is directly linked with many of these goals: most clearly clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), industry, innovation, and infrastructure (SDG 9), and sustainable cities and communities (SDG 11). Including SDG principles in engineering programs would help to guarantee that graduates not only have disciplinary skills but also the ethical and sustainable competencies needed for facing complex global issues. Recent studies of student engagement with digital tools reveal that perceived usefulness and motivation are key mediators of technology usage among engineering students [3].

There are few empirical studies that report on the impact of SDG-centered pedagogy in terms of longer-term competency development. Environmental sustainability

(SDGs 6, 7, 13, and 15) is the most addressed element, whereas social justice (SDGs 5, 10, and 16) and governance mechanisms (SDG 17) receive less attention in this regard.

The intent of this study is to address these research gaps by proposing an integrated contextualized model for mapping pedagogy with the ESG framework based on SDGs that links curriculum development, faculty development, and ongoing assessment of the SDG competencies.

4 RESEARCH METHODOLOGY

The study is conducted with a qualitative and exploratory methodology, studying pedagogical practices and organizational mechanisms for embedding the SDGs into engineering education. The methodology includes:

- Document Analysis: Study of the curricular frameworks, the accreditation requirements, and institutional reports on the integration of sustainability in engineering programs.
- Comparison of Case Studies: An examination of international case studies (European, Asian, and overall models of collaboration) where this type of education, focusing on the SDGs, has been undertaken successfully.

5 LITERATURE ANALYSIS

Adopted in 2015, the United Nations' SDGs are an overarching call to action on some of the world's biggest challenges, including poverty, inequality, energy, climate change, and environmental degradation. University engineering projects, especially project-based learning (PBL) and interdisciplinary collaboration, find an easy tool to implement SDGs in education. By working on projects, conducting academic research, and engaging with communities in the real-world aspects of work, students develop the capabilities to design and contribute toward sustainable futures. Table 1 illustrates the application of SDGs in engineering education based on universities' project examples.

Table 1. Application of SDGs in engineering education

SDG	Focus Field	Example of Project-Based Learning	University	Source
SDG-1: No poverty	Poverty reduction	Design affordable housing systems for rural areas	York University, United Kingdom	[4]
SDG-2: Zero hunger	Agriculture	Solar powered cold system for rural food storage	IIT Kharagpur, India	[5]
SDG-3: Good health and well-being	Biomedical	3D-printed prosthetics	University of Toronto, Canada	[6]
SDG-4: Quality education	Inclusive learning	Develop low-cost digital STEM kits for under-resourced schools	MIT D-Lab, United States	[7]
SDG-5: Gender equality	Gender inclusion in engineering	Integrate gender-sensitive design into curricula	Universitat Politècnica de Catalunya, Spain	[8]

(Continued)

Table 1. Application of SDGs in engineering education *(Continued)*

SDG	Focus Field	Example of Project-Based Learning	University	Source
SDG-6: Clean water and sanitation	Water access	Design portable water filtration systems for communities	University of Virginia (PureMadi), United States	[9]
SDG-7: Affordable and clean energy	Renewable energy	Solar microgrids for villages	University of Strathclyde, Scotland	[10]
SDG-8: Decent work and economic growth	Sustainable enterprise	Design sustainable small industries and fair-trade supply chains	York University, United Kingdom	[4]
SDG-9: Industry, innovation and infrastructure	Sustainable design and smart infrastructure	Design local transport systems with IoT sensors	TU Delft, Netherlands	[11]
SDG-10: Reduced inequalities	Social inclusion and accessibility	Design inclusive transportation systems	ASEE-SE, USA	[12]
SDG-11: sustainable cities and communities	Urban resilience	Smart mobility plans to cut congestion and emissions	Chalmers University of Technology, Sweden	[13]
SDG-12: Responsible consumption and production	Circular economy	Campus waste-tracking app to boost recycling	National University of Singapore (NUS), Singapore	[14]
SDG-13: Climate Action	Mitigation and adaptation	Model low-cost flood barriers and green housing	Imperial College London, United Kingdom	[15]
SDG-14: Life below water	Marine conservation	Remote sensing for reef water quality	University of Queensland, Australia	[16]
SDG-15: Life on land	Ecosystem restoration	Drone-enabled monitoring reforestation	ETH Zurich, Switzerland	[17]
SDG-16: Peace, justice and strong institutions	Governance and civic engagement	Design civic-tech tools for transparency and local governance	Auburn University, United States	[18]
SDG-17: Partnerships for the goals	Collaboration	Coordinate cross-university sustainable design projects	Global E3 (IIE)	[19]

6 DISCUSSION AND ANALYSIS

The inclusion of the United Nations SDGs in engineering education marks a shift from business-as-usual toward more sustainable, ethical, and globally competent higher learning. According to the literature, engineering programs have traditionally concentrated on technical knowledge and problem solving. However, global challenges such as climate change (SDG 13) and clean energy (SDG 7), reduced inequalities (SDG 10), and strong institutions need a more comprehensive approach that could accommodate environmental, social, and governance (ESG) dimensions [1].

Although there is clear convergence between SDGs and engineering outcomes, curriculum overload and faculty preparedness are significant obstacles. Furthermore, assessment instruments privilege quantitative results over qualitative ones in ways that do not lend themselves to assessing competencies such as ethical reasoning and systems thinking. Institutional practice innovations, such as AI-powered platforms for creative collaboration, signal new governance models that engineering education must embrace [20]. Additionally, institutional contextualization is addressed since global SDG frameworks must be adapted to local environmental and socio-economic settings. However, the use of strategic mapping, human capacity building, and multi-stakeholder collaborations provides an opportunity

for scale. PBL is an effective pedagogical tool aimed at linking SDG theory and applied engineering practice, providing the student with the role of actor in a sustainable transition. When these efforts are made in harmony with ESG considerations, they give rise to engineers capable of balancing innovative breakthroughs on one hand and prioritizing ethics on the other, efficiency balanced with equity, and progress that is constantly measured against planetary stewardship. The strengths, weaknesses, opportunities and threats of integrating the SDGs within engineering education are shown in Table 2.

Table 2. SWOT analysis of integrating SDGs into engineering education

Strengths	Weaknesses
The inclusion of the SDGs in engineering studies adds relevance and ethics-based direction to technical education. The SDGs present an internationally agreed upon framework for mapping construction education against sustainable development priorities. Students are encouraged to engage in interdisciplinary open system thinking that facilitates linking engineering design to social-ecological issues. Research suggests that students report higher levels of motivation when they address complex real world sustainability problems and experiential learning. Furthermore, universities that incorporate SDGs in their teaching and research fortify their institutional brand name to attract international collaborations, increase employability of graduates in sustainability demanding industries [21].	Curricula are already dense with technical content and have little space for sustainability-related material. Faculty preparedness is another challenge: Engineers were usually not trained in sustainability science, or pedagogies such as project-based learning and service-learning. It's one of the many reasons why our understanding and assessment of sustainability competencies such as ethical reasoning, system thinking or social impact is still so complex and qualitative. Without robust institutional coordination, integration will remain fragmented or symbolic [22].
Opportunities	**Threats**
The SDGs offer possibilities for pedagogical innovation, research collaboration, and global engagement. Embedding the SDGs helps to promote shift towards Project-Based Learning, experiential education, and community-based project work to link theory and practice. Online simulations and international classrooms support these efforts by bringing together colleagues from all over the world to tackle sustainability issues. The integration of SDG-related projects prepares students to develop competencies in ethical decision-making, teamwork, and innovation skills that are essential for future engineers [23].	The rigidity of accreditation may discourage flexibility, through a focus on physically measurable competencies at the expense of humanistic and ethical learning goals. When the global SDG goals and local educational priorities do not align, it could result in a tokenistic implementation or "SDG-washing", where universities adopted sustainability without actual transformation [24]. Resource disparity among the institutions in the Global North and South can perpetuate the educational divides and constrain the scaling of SDG pedagogy.

7 FINDINGS

The findings of the study indicate that impactful integration of the SDG agenda in engineering education will arise from an open, adaptive, and cross-disciplinary integrative institutional environment. The focus areas of engineering programs differ vastly, ranging from civil and mechanical engineering to computer science and bioengineering, but all can realize the SDGs when we allow curriculum design to become context specific.

Dynamic curriculum mapping facilitates the matching of outcomes with their related SDGs. For example, a civil engineering program could incorporate the discussion of SDG 6 (Clean Water and Sanitation), and/or SDG 11 (Sustainable Cities and Communities). An electrical or a mechanical program would have the opportunity to address SDG 7 (Affordable and Clean Energy) or perhaps SDG 13 (Climate Action).

Engagement with sustainability also seems to be an issue as far as the perceived focus on institutional barriers is concerned, meaning those who create centers for sustainability, SDG coordination committees, or cross-faculty task forces. These create structures that both encourage faculties to engage with each other and bring more training for faculty in sustainability-related issues and student initiatives. Collaboration with industry and national government bodies would also contribute to more academically relevant learning outcomes, making them even more compatible and usable within industrial settings. In the end, flexible institutional models create a culture of sustainability awareness among engineers who will be change agents in any sector [2].

8 RECOMMENDATIONS

Systemic integration between vision, pedagogy, and assessment of mission-driven institutional learning goals is a prerequisite for the successful integration of the UN SDGs in engineering education. First, links between the SDGs and course learning outcomes at the program level need to be established, primarily because universities map their programs strategically, which is subsequently used for coherence assurance across curricula and syllabi relevance. Second, faculty development is essential; workshops, interdisciplinary venues, and communities of practice can support teachers who are navigating the transition toward sustainability-based teaching by building comfort and competence. Third, innovative formats, sustainability clubs, hackathons, and challenge-based learning can enhance students' engagement in such a way that will compel them to take ownership, and which may result in creative solutions for the real-life sustainability scenarios. Fourth, forming partnerships with industry and government and non-profit partners creates real-world project contexts that connect in-class learning to practice and align with an experiential or problem-based model of learning. Finally, the current mixed methods of evaluation, using surveys and reflective portfolios, project deliverables, and stakeholder feedback, continue to guarantee an appropriate evaluative system within which progress can be measured and capable of responding to institutional as well as social needs. Adhering to these recommendations will, in turn, contribute to universities' capacity to develop engineers who are not only technically competent but also possess moral, environmental, and societal competence, thus becoming more effective in addressing the SDG challenges around the world.

9 CONCLUSION

The inclusion of the SDGs in engineering education represents a profound change from technical retention and disciplinary orientation to a value-based and sustainability-driven pedagogy. This study reveals that engineering, as a profession, has an active role in the global sustainability agenda, affects SDGs directly, and highlights the role of PBL as an active learning methodology for promoting an SDG mindset within educational programs and constructing opportunities through

practice-based projects. The limitations of staff skills and poverty of assessment practices mean that SDG and ESG principles have not been embedded systematically across courses. Managing these challenges will necessitate leadership from universities, faculty development programs, and further collaboration with industry, government, and civil society. Introducing the SDGs into our teaching is a conclusion that has been led by my research if we are serious about educating engineers who can help us move toward a world that is more sustainable, fairer, and more resilient.

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11 AUTHORS

Alaeddine Boubaker is a DBA candidate at the European School of Data Science and Technology. His research interests focus on the intersection of Artificial Intelligence, sustainability reporting, and supply chain optimization. He is the founder and lead developer of EcoScopeAI, an AI-augmented carbon accounting prototype designed to support SMEs in aligning with international sustainability standards such as ISO 14064 and ISO 14067. He has received multiple international awards for his applied AI research, including recognition in Supply Chain Management (Dubai) and Fraud Detection using AI (Salamanca, Spain) (E-mail: ala.boubaker@gmail.com).

Ahmad Shaheen is with the College of Management and Technology, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt (E-mail: ahmad.yahya.shaheen@aast.edu).

Marcellin Yovogan is with the Faculty of Economics and Business Administration, Sofia University "St. Kliment Ohridski", Sofia, Bulgaria (E-mail: myovogan@feb.uni-sofia.bg).

Mostafa Mohamad is with the College of Interdisciplinary Studies, Zayed University, Dubai, United Arab Emirates (E-mail: mostafa.mohamad@zu.ac.ae).

Aftab Haider Rizvi is with the Vijay Patil School of Management, DY Patil University, Navi Mumbai, India (E-mail: aftab.rizvi@dypatil.edu).

Anuj Kumar is with the Faculty of Management Studies, Marwadi University Research Centre, Marwadi University, Rajkot, Gujarat, India (E-mail: anuj.kumar@marwadieducation.edu.in).