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SPECIAL FOCUS PAPER

Transforming Engineering Pedagogy through the Lens of the Sustainable Development Goals

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ABSTRACT

Transforming engineering pedagogy is imperative in an era defined by global sustainability challenges. The United Nations' Sustainable Development Goals (SDGs) offer innovative teaching methodologies by embedding necessary competencies to tackle complex virtual and real-world problems. The paper integrates engineering courses with SDG-6, SDG-7, SDG-9, and SDG-11. By viewing education pedagogy through the lens of the SDGs, this paper positions the shift from the traditional content-based model towards project- and problem-based models that cultivate ethical solutions, critical thinking, interdisciplinary collaboration, and the transformation of scholarly, industrial, and societal perspectives. At a policy level, this transformation entails reforming the curriculum and assessment framework that values both societal impact and technical competence. By viewing engineering education through the lens of the SDGs, this study positions pedagogy as a catalyst for preparing future engineers not only as innovators but also as responsible agents of sustainable global development.

KEYWORDS

engineering pedagogy, higher education policy, sustainable development goals (SDGs)

1 INTRODUCTION

Technological advancements have led to the transformation of teaching methods, enabling state-of-the-art pedagogies in the field of education. The teaching fraternity had adopted distinct pedagogies, curricula, and learning process approaches to inspire the quality of student engagement and adopted Outcome-Based Education (OBE). OBE acts as a facilitator for promoting quality and sustainable learning models, especially in engineering education [1]. The paradigm shifts from a traditional teacher-centric teaching approach to a student-centric education that emphasises student autonomy, real-world implications of knowledge, and project-based learning methods. India's National Education Policy 2020 (NEP, 2020) emphasises project-based learning and significantly improves engineering education outcomes.

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Many engineering institutions still emphasise technical skills, including simulation workshops, design method studies, time management studies, and equation mastery, over environmental concerns and social responsibility. [2] argued that inequality in climate injustice, human rights, and sustainability has increased awareness among engineering scholars to develop new pedagogy and an ethical framework to prepare for global settings. There is an increase in global attention to attaining SDGs in the engineering domain, predominantly from 2022 to 2024 [3].

Very few Indian studies have researched attitudes of engineering students towards project-based learning. The present engineering academia, campus ecosystem, pedagogy alignment, and infrastructure require a drastic transformation to support a project- and problem-based learning model. The project- and problem-based learning model fosters critical thinking and promotes the real-world application of coursework taught. Project-based learning enhances soft skills, fosters engagement, and promotes higher-order thinking skills, ultimately improving career prospects [4]. The interest of engineering faculties also plays a significant role in implementing and integrating into engineering curricula. This underscores the noteworthy receptivity to project- and problem-based learning models. A study on the perception of engineering educators in South India reveals that the precise application of project-based learning is essential. However, time is the most significant pain point [5]. The new pedagogy framework could treat the Sustainable Development Goals (SDGs) as a canvas model, rather than a traditional content model.

The introductory section above outlines the significance of engineering pedagogy in contributing to the achievement of the SDGs. This study aims to simplify each engineering specialisation that incorporates sustainability by examining the competencies, skills, and attitudes developed within its set of courses. The paper adopts a qualitative approach to collect the literature review and synthesise the different approaches to engineering specialisation within the scope of the research objectives. Standard databases, such as Scopus and Google Scholar, were examined to understand the current state of engineering pedagogy relevant to the Sustainable Development Goals.

The paper underlined the following objectives:

1. To explore the role of engineering pedagogy in attaining the SDGs.
2. To integrate SDGs in engineering pedagogy in attaining the SDGs.

2 ENGINEERING'S PEDAGOGY CONTRIBUTION TO ATTAINING THE SDGs

Engineers are considered the prime drivers for achieving the 17 SDGs. The integration of critical consciousness theory with engineering pedagogy can contribute to achieving gender equality (SDG 5) in crisis-affected communities, areas affected by armed conflict, and regions impacted by natural disasters [6]. In 2015, the United Nations General Assembly adopted "United Nations Resolution 17" to provide a blueprint, "plan for people, planet, and prosperity." It addresses various development areas such as quality education, food, energy, water, and sanitation, where STEM (Science, Technology, Engineering, and Mathematics) disciplines contribute to support the achievement of these goals. In 2019, UNESCO declared "World Engineering Day for Sustainable Development" to highlight the role of engineering in promoting human well-being. On this basis, many universities are transforming their pedagogy, reassessing their OBE, and aligning their universities' values and principles with SDG targets 6, 7, 8, and 11. Women engineers demonstrate a more substantial commitment to sustainable development projects than male engineers, contributing to both social and environmental aspects [7]. Browser-based WebVR and wearable sensors advance quality education (SDG 4), bridge skill gaps, generate employment opportunities, and provide job-ready education (SDG 8). Low-cost immersive learning platforms enhance engagement, promote the ethical handling of biometric data, and foster greater motivation [8]. The most closely linked SDGs with engineering curricula are SDG 6, SDG 7, SDG 8, and SDG 11.

SDG-6 (Clean Water and Sanitation)
Goal: To ensure the availability of clean water and sanitation for all.
SDG-7 (Affordable and Clean Energy)
Goal: To ensure affordable, reliable, and sustainable energy for all.
SDG-8 (Decent Work and Economic Growth)
Goal: Full productive and decent work for all.
SDG-11 (Sustainable Cities and Communities)
Goal: Make cities safe, resilient, and sustainable with planned infrastructure.

Semester projects and a problem-based learning approach, spanning three years of the computer engineering degree, demonstrate a positive contribution towards achieving the SDGs. The knowledge of the SDGs among engineering students is also of great importance in bridging the gap in sustainable literacy and skills to achieve the SDGs. The results for engineering students indicated that they are aware of the SDGs at a superficial level, with low understanding of subgoals (Kirupa Priyadarsini et al., 2024). However, the engineering courses and universities demonstrated a willingness to learn and integrate the SDGs into their engineering curricula. Now, the question arises: how can engineering students be trained and prepared to contribute to the SDGs and acquire the necessary skills and competencies for this purpose?

3 WHAT WILL THE ENGINEER OF TOMORROW LOOK LIKE

Millennials (1980–1996) will comprise three-quarters of the global workforce, while Generation Z (1997–2012) will be young entry-level engineers. With great disruptors like Society 5.0, political change (terrorism and war), climate change (extreme weather conditions), economic instability (the Great Resignation), regulatory restrictions (traffic wars), OpenAI, and 5G and beyond evolving and penetrating across the market, industry, and culture. These changes prompt professionals to reevaluate their competencies to meet the demands of an intelligent working environment. This new order of work relies intensely on relationships between humans and technology. A new set of competencies among engineering students will be authoritative for navigating challenges in 2030.

The "new collar jobs" emphasise practical skills over conventional certificates and diplomas. The "Skills-First" approach model fosters diversity in socioeconomic backgrounds, promotes adaptability, and serves as a bridge to a long-term career ladder, offering contributions to the SDGs without the burden of traditional education.

In the context of Industrial 4.0, [9] identified 20 characteristics of innovation skills one should possess, including communicator, responsible, visionary, risk-taker, and analytical. Furthermore, achieving society 5.0 skills, the conscious integration of pedagogy design, and a transformation of higher education institutions (HEIs) are desirable. Specialisation of an engineer, such as Computer Science, Industry 4.0, Artificial Intelligence, Society 5.0, and Sustainability [10]. Data literacy, problem-solving, creative thinking, and programming skills are the most recognised skills for employability in the 21st century. [11].

The quality of engineering graduates is generally certified through the accreditation of institutions and the design of pedagogical approaches. The disciplines of Civil, Mechanical, Environmental, Electrical, Chemical, and Computer Sciences are common; however, new emerging specialisations, such as Artificial Intelligence, Cyber Security, Data Science, and Biomedical Engineering, have few formal regulations. Table 1 maps the skills required for sustainability and the mindset of engineering students needed to achieve the SDGs.

Table 1. Engineer specialisations, skills, and mindset for SDGs

SDGs link	Engineering Specialisation	Skills for Sustainability (Problem-Solving + Technical)	Soft Skills (Engineering Mindset)
SDG 6, 9, 11, 13	Civil	Infrastructure design-green and sustainable building, Urban planning, risk reduction for any disaster, eco-friendly construction materials, an efficient water supply, and a sanitation system	Teamwork skills, stakeholder engagement mindset, communication skills, leading the construction with ethical standards, and promoting inclusive practices
SDG 7, 9, 12	Mechanical	Energy-efficient machinery, developing renewable energy-based technologies (bioenergy and solar), green mindfulness practices, and circular economy behaviours like reuse and recycling	Adapts and is open to green technologies, an innovative mindset, Time management skills, resilience and agility in projects, and collaboration with industries
SDG 7, 9, 11	Electrical & Electronic	IoT for smart cities, smart disposal of electronic devices, minimising electronic devices for the circular economy, strong cybersecurity, and smart grids for energy storage	Data Analytics, AI Algorithms, Communication and Continuous Learning, Green skills awareness, Holistic approach skills
SDG 6, 13, 14, 15	Environmental	Carbon footprint capture, Biodiversity assessment, Pollution control, waste management, green chemistry	Cultural sensitivity, NGOs, and communities' collaboration, ethical and values-orientated
SDG 3, 6, 12, 13	Chemical	Specialised skills in thermodynamics, AI, and data analysis to optimise resource efficiency and Safety process mechanisms.	Teamwork, communication of risks and hazards associated, micro-management skills, adaptability to laws and regulations
SDG 4, 8, 9, 16	Software/Computer	Digital twins' technology, AI, and Big Data understanding, Smart cities, blockchain technology, and awareness on e-learning platforms	Learning attitude, ethics and transparency in using AI and IoT, Trustworthiness, Creative problem-solving, and cross-cultural management
SDG 3, 9	Biomedical	Digital health devices and technology skills, proper disposal of biomedical wastage, and usage of biocompatible resources	Patient-centric decisions, social and ethical responsibility, Empathy skills, innovation in implementation

Source: Author's own work.

4 INTEGRATION OF SDGs INTO ENGINEERING PEDAGOGY

Traditional engineering education is criticised for being focused on expertise in mechanical or electrical engineering. The pedagogy of the subject course prioritises abstract mathematical principles over real-world cases. The consideration of a social, environmental, or ethical solution is less. The inclusion of the SDGs perspective in a new pedagogy would enhance cognitive skills and promote a balanced state of mind through the following conduct:

1. **Interdisciplinary approach:** Emerging environmental issues, such as climate change (SDG 13), sustainable cities (SDG 11), and providing clean water (SDG 6), can be addressed through the correct application of skills and knowledge acquired by interdisciplinary engineers from environmental, chemical, civil, and political backgrounds.
2. **Project- and problem-based learning:** Learning through hands-on projects and problems of real situations, like environmental awareness campaigns, restoration of gardens, pitching ideas on community-centric challenges related to health issues (SDG 3), and digital skills (SDG 4).
3. **Ethical work standards:** focused on human equity (SDG 5), a strong sense of using artificial intelligence ethically, and against fraud.
4. **Global citizenship:** Understanding global issues fosters a transformative learning experience by utilising open-access resources, open assignments on renewable energies, fellowships, collaborations, and open-licensed material (SDG 4).
5. **Pedagogical approach:** The change in the teaching method could contribute to achieving the SDGs. Table 2 highlights the different teaching models and their implications for the SDGs among engineers.

Table 2. Integration of SDGs into engineering pedagogy

Pedagogical Model	Explanation	SDGs Implication	Teaching Material
Flipped Classroom	Students are aware and engaged with subject content before class and use class time for flexible learning.	Quality Education (SDG 4) Collaborative projects, Discussions, Complex Problem-Solving Critical Thinking Skills	Pre-recorded sessions
Design Thinking	Problem-solving steps with Human-Centered solutions or Labs harness the power of the iterative process of testing and prototyping.	All Core SDGs Cross-Disciplinary Collaborations Iterative Problem Solving Re-imagining Process, People, and System	Design Thinking Toolkit
Project-Based Learning	Introduce analytical and meaningful real-world project situations that accelerate the critical experience of taking responsibility and making decisions.	Quality Education (SDG 4) Industry & Innovation (SDG 9) Customised SDG based on the project problem theme	Project Design Assessment based on solution approach
Community Engagement	Integrates community service with an academic pedagogy, focusing on critical situations like local infrastructure, education, medicines, and mental awareness	No Poverty (SDG 1) Inequality (SDG 10) Cities and Communities (SDG 11) Empathy skills Resilience Skills Cultural Competency Skills Life Skills	Assessment with an external and internal supervisor using real-life situation factors, problems, and their solutions
Case-Based Learning	Analysis of real-world cases on engineering and social successes and failures	Responsible Consumption (SDG 12) Institutional Development (SDG 16) Failure Coping Skills Ethics Skills	Cases on Government Policy and Ethics

Source: Author's own work.

The SDG in the engineering curriculum is not only about adding content or context, but it is also about transforming skills and knowledge to comprehend the "why" and "how" of goals. The correct and timely implementation is essential.

First Year: SDGs as an introductory framework to understand the "Why" of Engineering Context.

Second Year: Re-contextualise the "What" of SDGs as a Core Technical Course, and frame it into specialised engineering courses like SDG 13 Climate-prone areas and SDG 7 for using affordable energy in remote areas.

Third Year: Make a mandatory multi- and transdisciplinary project that directly addresses one or more SDGs. It would promote the "How" and "Who" context of both technical and non-technical environmental learning.

Fourth Year: Map the assessment of a new generation of engineers who are not only technically competent but also empathetic and environmental thinkers.

5 CRITICAL CHALLENGES IN IMPLEMENTING SDGs

Despite the emerging demand and discussions, the critical challenges in integrating SDGs through an engineering pedagogy lens could be broken down into the following categories:

1. **Institutional Challenges**

   Most institutions lack **digital sustainability**, which is the most important driver for implementing projects and assignments. The lack of sufficient resources, green chemistry labs, and simulation centres hinders pedagogical approaches.

   The Bureaucracy Administration System tightens the transfer of knowledge, resources, and technology in the system, which in turn makes it more challenging to run at pace and adopt new content on time.

   Inadequate Internet services hamper the continuity of using 5G and electricity-based laboratories.
2. **Students' Weak Graduate Competences and Skills**

   The skill gap is widening the gap between the demands of industries and the present skills of graduates. The future engineers not only need technical skills but also non-technical, social, and ethical skills.
3. **Pedagogy and Curriculum**

   Misalignment with SDG needs to anticipate the right competencies taught in the engineering courses and the strategic, anticipatory, and cognitive skills needed to address the interconnected challenges of the SDGs.

   Re-engineering leaves limited room for additional sustainability-focused course modules. Introducing SDGs requires a change in rethinking course design, engineering fundamentals, and assessment criteria.

   Faculty preparedness is also a challenge, as educators are often highly educated but may lack experience in teaching sustainability, ethics, and social responsibility. Additionally, the required time, reading materials, assessment tools, and institutional collaboration are not always accessible.

Finally, the SDGs are international in scope, and the global and local divides create an additional gap in achieving the goals. The global economic war, culture, changing world order, and climate change are a few external factors that impact the attainment of goals by 2030.

6 CONCLUSION AND LIMITATION

Keeping the SDGs in mind, this study proposes that engineering pedagogy can be successfully implemented to bridge the gap between traditional academic curricula and the needs of futuristic engineers. The study develops an engineering framework that incorporates various skill sets across different engineering disciplines. It will bring academia, educators, stakeholders, students, and education policymakers together on one page to adopt a pedagogy that generates employability and sustainability skills. However, the study is limited in its research approach and engineering specialisation. The high demand for robotics, genetics, aerospace, circular economy, AI, and machine learning engineering is increasing the scope of engineers' specialisation.

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