DYNAMIC INTEGRATION OF SUSTAINABILITY AND CLIMATE CHANGE IN ENGINEERING CURRICULA VIA CDIO

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ABSTRACT

This paper explores the transformative potential of the CDIO (Conceiving, Designing, Implementing, and Operating) approach in adapting traditional engineering programs to accommodate the needs for sustainability and climate change perspectives. Integrating those aspects is imperative today since engineers play a pivotal role in addressing the industry's environmental impacts and meeting the demands of a changing energy landscape. Equipping students with these skills is essential to ensure graduates are well-prepared to balance industry needs with environmental responsibility. The CDIO approach, rooted in global collaboration and practical problem-solving, offers a flexible framework that aligns with the growing needs of the industry since it allows educators to seamlessly incorporate new concepts into the curricula while connecting the vertical and horizontal educational approaches. One innovative idea is to leverage the CDIO or Project-Based Learning (PBL) concept to create dynamic engineering curricula. Our experience from the Australian University in Kuwait includes case studies of PBL courses from the Petroleum Engineering Program that incorporate various sustainability aspects. In these case studies, students ventured beyond their usual curriculum, acquiring knowledge that extended to novel and essential elements. Empirical evidence from pre- and post-surveys showcases PBL's significant impact on enhancing students' understanding of sustainability concepts within engineering curricula. The study underscores the value of hands-on, project-driven learning in fostering a holistic and environmentally conscious approach among engineering students. In conclusion, this paper discusses how CDIO, emphasizing real-world application and open-architecture design, can dynamically reshape engineering education. The case studies demonstrate a successful and applicable approach, offering students a promising opportunity for skill development and acquiring new learning outcomes beyond the traditional curriculum. This dynamic adaptation promises to produce a new generation of engineers better prepared to navigate the ever-growing industry while practicing environmental stewardship and sustainability.

KEYWORDS

Sustainability, Climate Change, Engineering Education, Dynamic Curricula, Project-Based Learning, Standards: 1, 2, 3, 8, 11.

INTRODUCTION

Engineering education is at a crossroads that necessitates a significant shift. Traditional programs emphasize technical competence and lack critical viewpoints on sustainability and climate change, leaving young engineers unprepared for the ever-growing world. This mistake not only jeopardizes their holistic training but also risks their capacity to navigate a world increasingly affected by environmental issues. **Figure 1** depicts the present gaps in standard engineering courses regarding sustainability and climate change views.

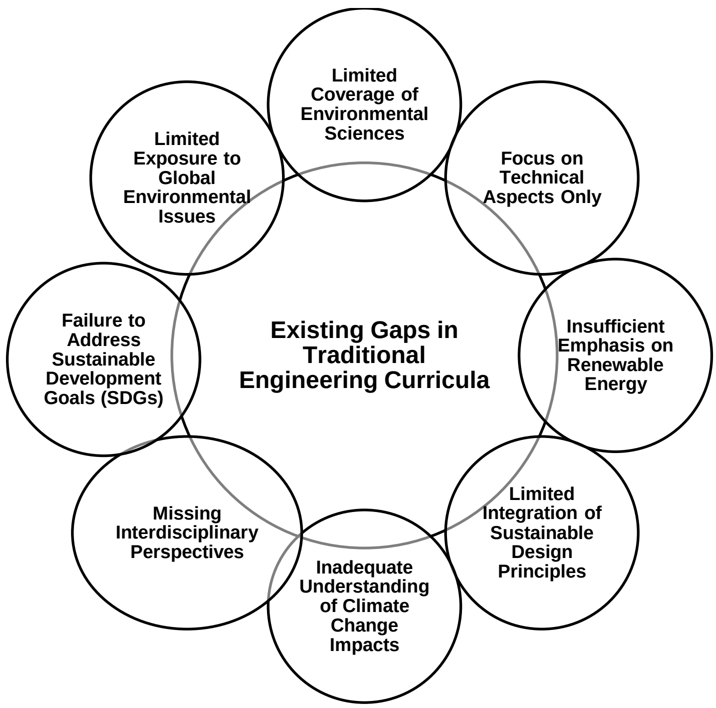

Figure 2. Deficiencies in Traditional Engineering Curricula: Gaps in Sustainability and Climate Change Perspectives

These curriculum gaps exclude critical disciplines such as climate science and renewable energy, leaving a deficit in addressing critical global environmental challenges. Engineers, however, have a crucial role in addressing these issues, which impact energy consumption, resource usage, and sustainable infrastructure.

Sustainability integration in engineering education fits with ethical duties and the Sustainable Development Goals (SDGs), addressing industrial demands for sustainable solutions. It's more than just a matter of curriculum; it's an ethical and cultural imperative enabling engineers to design a more sustainable future for the industry and the global community.

There is a distinct lack of emphasis on sustainability and environmental consciousness in mechanical and software engineering schools. While mechanical engineering avoids environmental issues in favor of specific green technology electives, software engineering lacks standardized instruction in Requirements Engineering. These difficulties highlight the need for more comprehensive techniques for integrating sustainability into engineering education (Daun et al., 2023; Sprouse III et al., 2021).

Simultaneously, initiatives to include sustainable development into curricula are emerging, utilizing frameworks such as CDIO and the UN Sustainable Development Goals (SDGs). Despite efforts to connect digital and human skills to the SDGs, obstacles remain, necessitating a more comprehensive strategy to integrate sustainability deeply within engineering education (Cheah et al., 2022).

Meanwhile, gaps in sustainable integration emerge in civil engineering, whether aligned with accrediting standards or not. This disparity emphasizes the critical need for more robust tactics in engineering education (Gutierrez-Bucheli et al., 2023). The changing energy economy challenges Petroleum Engineering programs; therefore, updating the petroleum engineering curriculum by increasing content, including renewables, and considering artificial intelligence and machine learning is critical nowadays. It underlines the long-term value of petroleum engineering skills, which are applicable even in low-emission technology, and advises programs as they traverse this changing energy landscape (Al-Shalabi et al., 2023). There were some interesting results in a recent SPE survey examining how the energy transition affects petroleum engineering education. According to the poll, 95% of petroleum faculty members favor curricular modifications prioritizing sustainability and clean energy. Even though the majority support including data analytics, clean energy, and sustainability in the curriculum, many still expressed worries about their level of readiness. They emphasized the need for more opportunities for industry networking (Fahes et al., 2023). On another note, sustainability is crucial in navigating the evolving Energy Internet landscape in electrical engineering. A recent study suggests a dual-focused curriculum reform to embed sustainability, better equipping engineers for this transformative phase (Zhang et al., 2023). Consequently, a significant storyline emerges, calling for reforming organizational culture within institutions to promote sustainability (Konst et al., 2022). Bridging the gap between institutional beliefs and activities toward sustainability creates a critical narrative that calls for additional research in climate change education (Hindley, 2022).

Amidst these challenges, ongoing efforts at the Australian University in Kuwait strive to integrate CDIO standard #1 on Sustainable Development throughout its engineering program. This ensures students develop solutions focusing on social, economic, and environmental responsibility, preparing them to address complex sustainability challenges in their engineering practices. The fundamental principles of the CDIO approach include four phases. For the "Conceive" phase, the students are encouraged to identify and understand real-world problems by developing a deep understanding of the problem context while considering constraints and defining the scope of the engineering challenge. Regarding the second phase, "Design", the students are engaged in the design process by applying the previously acquired theoretical knowledge to develop an innovative solution for a problem. After that comes the implementation phase, where the students turn their design into a tangible prototype or a working model, which allows the students a hands-on experience to apply the acquired engineering principles and gain practical experience. For the last phase of this approach, which is the "Operate", the students will observe the performance of their design through testing and operating the implemented solution, which in turn will allow them to perceive the effect of their engineering decisions.

Consequently, the CDIO strategy emerges as a transformative force in this educational context since it represents a promising shift from traditional techniques, stressing hands-on, real-world learning. This is a critical framework for engineers tackling sustainability and climate change challenges. This paper contends that the CDIO approach, underscored by its emphasis on real-world application and practical problem-solving, holds promise in dynamically reshaping engineering education. The case studies presented herein serve as a testament to the efficacy of this approach in fostering skill development and acquiring new learning outcomes beyond the confines of traditional curricula.

INTEGRATION OF SUSTAINABILITY AND CLIMATE CHANGE: CASE STUDIES FROM THE AUSTRALIAN UNIVERSITY IN KUWAIT

The Bachelor of Engineering Technology curriculum at the Australian University in Kuwait contains three Project-Based Learning (PBL) courses offered in the program's 4th, 5th, and 6th semesters to complement the acquired fundamental knowledge received before or during each PBL course. Each PBL course consists of 75 hours and is worth 3 credits towards the completion of the program. The learning outcomes of these courses are summarized in **Table 1** below:

Table 2. Anticipated Learning Outcomes for the Project-Based Learning Courses

Level	Learning Outcomes
Project 1 (PBL) Semester 4	LO1. Recall required engineering and sustainability principles to solve well-defined real-world engineering project. LO2. Analyze well-defined project specifications for efficient technical and financial breakdown of the project. LO3. Design and develop a solution that is compliant with the required standards and practices. LO4. Iteratively evaluate and optimize solutions to improve efficiency and compliance through reflection. LO5. Practice project management, oral and written communication, and teamwork skills effectively.
Project 2 (PBL) Semester 5	LO1. Acquire required engineering and sustainability principles to solve well-defined real-world engineering project. LO2. Evaluate and analyze project specifications to organize and prioritize project tasks effectively, considering technical, environmental, and economical aspects. LO3. Synthesize compliant solutions that meet high standards and best practices in engineering. LO4. Critically assess and refine engineering solutions through iterative evaluation to maximize efficiency and ensure robust compliance. LO5. Manage project workflows and lead teams, facilitating high-level oral and written communication and collaboration.
Project 3 (PBL) Semester 6	LO1. Compile diverse engineering and sustainability principles to solve a broadly defined real-world engineering project. LO2. Critically dissecting and integrating project specifications with industry trends and forecasts, integrating technical, environmental, and economical aspects of the project. LO3. Develop sustainable engineering solutions in compliance with the highest industry standards and ethical practices. LO4. Critically evaluate and assess outcomes through reflective thinking for optimal performance and compliance. LO5. Develop a holistic project management approach by mastering leadership, collaboration, oral and written communication within the team and diverse stakeholders, inspiring innovation.

In this section, two case studies for two projects in the petroleum engineering program are presented and discussed, in addition to how they contribute to the transformative potential of

CDIO.

Case Study 1 - Sustainable Management of Oil and Gas Produced Water

The main objective of this project was to investigate the sustainable management and valorization of oil and gas produced water in Kuwait, addressing the challenges posed by the disposal of this wastewater because it is considered a significant environmental concern (El Achkar et al., 2024). The students were expected to recall, acquire, and compile the different engineering and sustainability principles to analyze, evaluate, and assess the problem and then develop and design a solution to address this problem.

The project focuses on the long-term management of oil and gas produced water, which is an essential aspect of environmental stewardship in the petroleum industry. In addition, it addresses the environmental concerns of improper disposal, directly aligning with sustainability goals. This shows a clear integration of sustainability and climate change perspectives embedded within this course. The project also integrates novel aspects into traditional engineering education by investigating cutting-edge treatment technologies and specific practices used in Kuwait for producing water management. It exemplifies the adaptability of the CDIO approach in incorporating contemporary environmental challenges into engineering curricula.

Table 2 below summarizes the contributions of such projects to the transformative potential of the CDIO approach.

Table 3. Contribution of the 1st Case Study

CDIO Approach	Contribution
C - Conceiving	As a part of the problem identification and holistic understanding, the students are expected to better understand the problem's scope by defining and characterizing produced water, discussing its composition, and highlighting potential environmental impacts. This is consistent with the CDIO approach's emphasis on real-world problem understanding.
D - Designing	The exploration of treatment technologies by investigating treatment technologies worldwide and those used in Kuwait gives students a broader perspective on available solutions and limitations. This investigation highlights the CDIO approach's emphasis on experimenting with various solutions.
I - Implementing	Considering the Energy-Water-Food Nexus when valorizing produced water to demonstrate a multidisciplinary approach, the students are encouraged to think outside the box and look for new ways to use a waste stream, which aligns with the CDIO approach's emphasis on practical applications.
O - Operating	The Hands-on experimental evaluation and analysis, such as assessing methane production via anaerobic digestion, requires hands-on application and observation. This is consistent with the CDIO approach's principle of learning through practice.

The sustainable management of oil and gas produced water case study demonstrates the CDIO approach's transformative potential in several ways. It actively incorporates sustainability considerations into engineering education and addresses real-world environmental challenges. This case study embodies the essence of a flexible, adaptable educational framework like CDIO by engaging students in problem identification, exploring diverse solutions, and conducting practical experiments related to sustainable development and climate change.

Case Study 2 – Sustainable Liquefied Natural Gas (LNG) Production Process

The main objective of this project was to examine the liquefied natural gas (LNG) production process, encompassing its significance within the energy industry, the intricacies of LNG liquefaction, factors influencing production, and its environmental impact. The students were expected to calculate the carbon footprint of LNG production after designing and simulating the LNG process using simulation software based on collected data from multiple sources, including industry databases and equipment manufacturers. In addition, the students were expected to explore carbon offset strategies such as reforestation projects, carbon capture and storage (CCS) technologies, and investments in renewable energy while assessing the feasibility of adopting cleaner energy sources to ensure a more sustainable future for LNG production.

The goal of integrating sustainability and climate change perspectives was directly addressed by the LNG project, which thoroughly investigates the environmental impact of LNG production, quantifies the carbon emissions, examines carbon offset strategies, and evaluates cleaner energy alternatives. This project also illustrates the adaptability of the CDIO approach and how traditional programs can evolve to include sustainability and climate change perspectives by involving students in evaluating environmental impacts and proposing sustainable solutions within LNG production. **Table 3** below summarizes the contributions of such projects to the transformative potential of the CDIO approach.

Table 4. Contribution of the 2nd Case Study

CDIO Approach	Contribution
C - Conceiving	Analyzing factors influencing LNG production and evaluating cleaner energy alternatives necessitates a comprehensive understanding, a hallmark of the CDIO approach's focus on "Conceiving and Designing." This multifaceted analysis cultivates a mindset in which students consider various parameters when addressing sustainability challenges.
D - Designing	
I - Implementing	The project immerses students in real-world problems, consistent with the CDIO approach's emphasis on practical problem-solving. Students gain hands-on experience addressing sustainability concerns by calculating carbon footprints and exploring mitigation strategies, an essential aspect of "Implementing and Operating" within CDIO.
O - Operating	

The project's emphasis on current industry practices and environmental impact directly relates to real-world issues. By incorporating this into the curriculum, the CDIO approach demonstrates its ability to adapt to industry needs while addressing pressing global concerns explaining the framework's relevance. In addition, this project initiates a paradigm shift in education by incorporating sustainability into a traditional engineering program. It exemplifies the CDIO approach's transformative potential in reshaping engineering education by adapting traditional curricula to align with contemporary global challenges.

The CDIO approach actively integrates sustainability and climate change perspectives into traditional engineering education. By engaging students in practical problem-solving, holistic analysis, and real-world applications within LNG production, this project embodies the essence of a forward-thinking, adaptable educational framework like CDIO.

Discussion on the Two Case Studies

Those two studies demonstrate how the CDIO approach can integrate sustainability and real-world problem-solving into engineering education. It enriches students' educational experiences and provides real solutions to major environmental concerns, demonstrating this teaching methodology's revolutionary potential. The above-mentioned case studies from the petroleum engineering program at the Australian University in Kuwait demonstrate this transformative capacity since they propelled students beyond conventional boundaries via Project-Based Learning (PBL).

One study addressed sustainable petroleum-produced water management within the Energy-Water-Food Nexus, a cross-disciplinary investigation not typically included in engineering education. This study not only aligns with SDG 6 (Clean Water and Sanitation) by addressing water-related challenges, but it also broadens students' understanding of other SDGs, such as SDG 7 (Affordable and Clean Energy) by emphasizing sustainable energy practices and SDG 13 (Climate Action) by emphasizing carbon-reduction strategies.

Similarly, research into Liquified Natural Gas (LNG) production covers a wide range of topics, including SDG 7 (exploring cleaner energy alternatives) and SDG 13 (integrating strategies to reduce environmental impact). Furthermore, this interdisciplinary project fosters innovative thinking, which aligns with SDG 9 (Industry, Innovation, and Infrastructure), and exposes students to broader global challenges, developing a holistic approach to sustainability in engineering.

These experiences demonstrate how the CDIO approach goes beyond traditional education, preparing future engineers to address multifaceted challenges across multiple SDGs, where the students learn about sustainability and how to achieve these goals by incorporating diverse aspects into their problem-solving approaches by participating in interdisciplinary projects and understanding the Energy-Water-Food Nexus. This incorporation into traditional engineering programs reflects the CDIO approach's efficacy in shaping engineers who can address environmental challenges holistically, fostering innovation, and achieving the United Nations' sustainable development goals.

PROJECT-BASED LEARNING: FUSING VERTICAL AND HORIZONTAL APPROACHES FOR SUSTAINABILITY IN ENGINEERING EDUCATION

The vertical and horizontal approaches can be used to integrate sustainability into engineering education (Tasdemir and Gazo, 2020). In the vertical approach, engineering programs could introduce standalone subjects or specializations exclusively focused on sustainability. These will offer students a broad understanding of sustainability's core principles, practices, and implications within the engineering setting. For instance, subjects may involve sustainable energy systems, environmental impact assessment, or green engineering solutions. These specialist courses enable students to delve extensively into sustainability issues, gaining expertise and a nuanced grasp of specific sustainability challenges. However, the vertical approach may confront challenges in transdisciplinary learning. Students could thrive in sustainability-specific knowledge but perhaps miss linkages to larger engineering fields. This compartmentalized structure could impair the comprehensive vision for addressing complicated, real-world situations.

In contrast, the horizontal approach incorporates sustainability concepts into existing engineering modules rather than segregating sustainability into separate disciplines. This approach incorporates sustainability principles within standard engineering curricula. Projects in subjects such as structural engineering or materials science, for example, may integrate sustainable design considerations or investigate environmentally conscious materials. This integration enables students to grasp how sustainability intersects with crucial engineering fields, creating interdisciplinary relationships. However, the horizontal approach may provide breadth at the sacrifice of depth. While students obtain a broad awareness of the application of sustainability across engineering fields, the concentration on individual sustainability themes may be less detailed than in dedicated sustainability courses.

The Role of Project-Based Learning (PBL)

PBL serves as an interface between these approaches since it provides a hands-on, immersive experience in which students work on projects entirely focused on sustainability in the vertical approach. These projects allow participants to put theoretical knowledge into practice by tackling real-world sustainability issues and cultivating specialized skills. PBL's horizontal approach (**Figure 2**) effectively integrates sustainability into existing projects or modules since it encourages students to regard sustainability as an intrinsic part of their primary engineering curriculum by including sustainability factors in traditional engineering projects, such as eco-friendly design considerations or renewable energy applications. This approach fosters multidisciplinary thinking by integrating sustainability themes with multiple engineering fields.

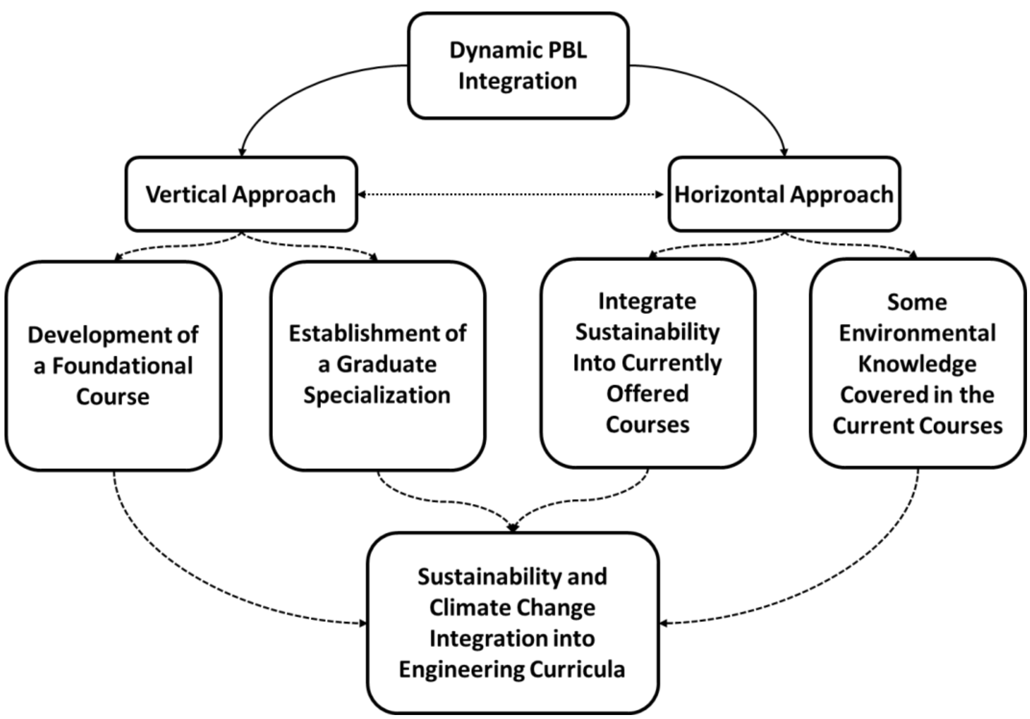

Figure 3. Integration of Sustainability in Engineering Curricula: A PBL Bridge between Vertical and Horizontal Approaches

Overall, PBL encourages students to connect meaningfully with sustainability when thoughtfully integrated into both vertical and horizontal approaches. In addition, it provides a pathway for students to comprehend, apply, and innovate sustainable solutions, thereby contributing to a comprehensive understanding of sustainability and its role in addressing global challenges within engineering curricula, whether through dedicated sustainability projects or infusing sustainability into traditional engineering modules.

ASSESSMENT OF KNOWLEDGE AND PERCEPTION: PRE AND POST INTEGRATION OF SUSTAINABILITY IN ENGINEERING CURRICULA THROUGH PBL

During the academic year 2022-2023, a set of five questions, with ratings ranging from "Very Low / Poor" at 1 to "Very High / Excellent" at 5, were asked to 40 participating students enrolled in the PBLs mentioned above to quantify the perceived changes in understanding, awareness, and applicability of sustainability and climate change concepts before and after the PBL project, enabling a comparative analysis of students' perspectives. The survey results were analyzed using statistical measures such as average and standard deviation to ensure clarity and reliability.

The tables below summarize the results of the two surveys administered to students to assess the integration of sustainability principles into engineering education via PBL. The surveys aimed to examine students' initial perceptions and understanding of sustainability concepts (**Table 4**) and assess the impact of the PBL integration on their knowledge and perceptions (**Table 5**).

Table 5. Pre-Survey Results on Sustainability Integration in Engineering Education

PBL Pre-survey	Avg. Students' Rating (Scale of 5)
Knowledge: On a scale of 1 to 5, how would you rate your current understanding of sustainability principles and their application in engineering projects?	2 ± 0.2
Awareness: Rate your familiarity with the relationship between engineering practices and their impact on climate change from 1 to 5.	2 ± 0.4
Perception of Sustainability Integration: On a scale of 1 to 5, how well do you feel your engineering education covers sustainability and climate change?	2 ± 0.4
Previous Exposure: Rate from 1 to 5 based on your previous engagement with coursework or projects explicitly addressing sustainability or climate change in engineering contexts.	2.5 ± 0.3
Expectations: Rate your expectations for gaining knowledge or skills through the upcoming PBL project integrating sustainability into engineering curricula from 1 to 5.	3 ± 0.3

Table 6. Post-Survey Results on Sustainability Integration in Engineering Education

PBL Post-survey	Avg. Students' Rating (Scale of 5)
Knowledge: How much has your understanding of sustainability principles improved after completing the PBL project? Rate from 1 to 5.	4 ± 0.1
Understanding: Has the PBL project enhanced your knowledge of the link between engineering practices and their impact on climate change? Rate from 1 to 5.	4 ± 0.2
Impact: Rate from 1 to 5 how the PBL project contributed to your knowledge of sustainability and climate change in engineering contexts.	4 ± 0.3

Perceived Relevance: Do you believe that integrating sustainability through PBL has increased the relevance of sustainability concepts in your engineering education? Rate from 1 to 5.	4.5 ± 0.3
Application of Knowledge: How confident do you feel in applying sustainability principles and considering climate change factors in future engineering projects after completing the PBL project? Rate from 1 to 5.	4 ± 0.1

The tables analyze students' pre-survey responses to specific questions about prior knowledge, awareness, perceptions, and expectations. This data is contrasted with the comparable post-survey results, demonstrating the shifts in students' understanding, awareness, and perceived importance of sustainability concepts after participating in the PBL effort. Before PBL, students understood engineering sustainability ideas poorly. Their baseline knowledge, climate change comprehension, and engineering curriculum sustainability were rated 2 out of 5. Even though they had taken sustainability classes, they were cautiously optimistic about the next PBL project.

Post-survey findings showed a considerable improvement. Students reported significant gains in all areas after the PBL assignment, and their sustainability knowledge improved from 2 to 4. Their grasp of the relationship between engineering practices and climate change and the implementation of sustainability concepts in engineering education improved to 4 out of 5. PBL integration made sustainability topics seem relevant, which was remarkable. Students rated sustainability as more important in engineering education at 4.5 out of 5. This indicates that the PBL approach successfully combined sustainability principles with engineering methods, making them more applicable to their area. Post-PBL integration improvements showed that hands-on, project-driven learning improves engineering students' understanding and appreciation of sustainability. The substantial positive shift in perceptions and knowledge highlights the potential of Practical learning methods like PBL in developing a more holistic and environmentally responsible approach within engineering curricula.

CONCLUSIONS AND PERSPECTIVES

To conclude, PBL acts as a bridge, allowing students to connect profoundly with sustainability in various ways. It facilitates the comprehension, application, and creativity of sustainable solutions, fostering a complete awareness of the role of sustainability in engineering education. The change in students' attitudes following PBL highlights the importance of hands-on, project-driven learning in creating a more holistic and environmentally conscious approach among engineering students.

Several critical perspectives are positioned to affect future sustainability integration into engineering education. It is essential to emphasize interdisciplinary collaboration across varied sectors, fostering holistic problem-solving skills for addressing complex sustainability concerns. Equally important is equipping educators with comprehensive sustainability pedagogy training, ensuring seamless course integration. Strengthening linkages with industries engaged in sustainable practices is vital, providing students with real-world project experiences that integrate academic understanding with practical applications. Continuous curriculum evaluation and enhancement are required to ensure relevance and innovation in adapting to evolving sustainability paradigms. Fostering worldwide collaborations and information exchange programs also broadens perspectives, enabling a better understanding of various sustainability scenarios. This multidimensional approach is crucial for successfully integrating sustainability into engineering education, and PBL appears to be a key tool for influencing future engineers' mindsets and establishing a strong commitment to addressing global sustainability concerns.

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