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Advancing Sustainability in Civil Engineering Technology through the Engineering for One Planet Framework

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Abstract

As global environmental challenges intensify, integrating sustainability into engineering technology education is increasingly critical. Yet, many programs lack comprehensive methods to embed sustainability principles, leaving graduates underprepared to address real-world environmental issues. Courses on sustainability often approach it in isolated or superficial contexts, unable to capture its complexity. The purpose of this study is to showcase one approach for embedding the Engineering for One Planet (EOP) framework into the Sustainable Building Practices course within the Civil Engineering Technology Department. The newly developed curriculum integrated learning outcomes from three EOP topics: Environmental Impact Assessment, Materials Selection, and Systems Thinking. Students were trained to conduct environmental assessments, select sustainable materials based on life-cycle impacts, and design buildings that align with ecological and social systems to promote durability, net-zero emissions, to promote long-term resilience while minimizing environmental and social harm. The new curriculum's effectiveness was assessed through a mixed-methods approach, combining quantitative retrospective surveys and qualitative photo-voice assignments. Quantitative results from retrospective surveys show significant improvement in learning outcomes across these topics, with Likert scores increasing notably after the course. Qualitative analysis of photo-voice assignments, informed by the *How Learning Works* framework, revealed three themes: Recognizing Value, where students highlighted the role of sustainability in reducing environmental and cultural impacts; Supportive Environment, which emphasized the importance of sustainable materials for safety, efficiency, and workflow; and Student Efficacy, demonstrating students' ability to apply the learning outcomes. These results indicate that embedding sustainability into engineering courses through the EOP framework promotes a comprehensive understanding of environmental systems, improves decision-making, and enhances students' readiness to address real-world challenges. This study provides a practical example of how the EOP framework can be integrated into a course to strengthen students' ability to address real-world sustainability challenges.

Keywords: Sustainability, Engineering Education, Engineering for One Planet, Civil Engineering Technology

1.0 Introduction

As global environmental challenges such as climate change, resource depletion, and ecological degradation escalate, there is a growing imperative to embed sustainability into engineering practices. Engineers play a critical role in addressing these issues by creating solutions that minimize environmental impact while promoting resilience and resource efficiency (United Nations, 2015). However, many engineering education programs fail to adequately integrate sustainability principles into their curricula, leaving graduates unprepared to address the complex, multifaceted challenges of the modern world [1].

Traditional approaches often relegate sustainability to peripheral courses or theoretical discussions, lacking the depth and integration required for students to develop practical, systems-oriented solutions [2]. This gap necessitates new frameworks to ensure future engineers are equipped with the skills to address environmental and social challenges holistically. The Engineering for One Planet (EOP) framework provides a structured approach to embedding sustainability into engineering education. It emphasizes core competencies such as systems thinking, environmental responsibility, and interdisciplinary problem-solving, aligning with the global emphasis on life cycle thinking and sustainable systems integration [3].

This study applies the EOP framework to the Sustainable Building Practices course within the Civil Engineering Technology Department, addressing a critical sector responsible for nearly 40% of global carbon emissions and significant resource use [4]. The curriculum revision focuses on three EOP competencies: Environmental Impact Assessment (EIA), Materials Selection (MS), and Systems Thinking (ST). These areas were chosen to address gaps in sustainability education and equip students with practical tools for assessing life-cycle impacts, selecting sustainable materials, and understanding the interconnectedness of building systems. Through a mixed-methods approach combining quantitative retrospective surveys and qualitative photo-voice assignments, this study evaluates the impact of these curricular changes. The findings contribute to the growing body of research on integrating sustainability into engineering education and provide a replicable model for broader implementation. See Engineering for One Planet (2020) for full framework details: https://engineeringforoneplanet.org/wp-content/uploads/EOP_Framework.pdf

2.0 Background

Sustainability in engineering is vital for addressing global challenges such as climate change, biodiversity loss, and resource scarcity. Engineers influence critical systems, from infrastructure to resource management, making their role essential in promoting sustainable development [5]. Despite this, traditional engineering education often emphasizes technical problem-solving over sustainability integration, leaving students unprepared for the complexities of contemporary environmental issues [6][7].

Recognizing this gap, global organizations such as UNESCO and the United Nations have called for engineering education to emphasize sustainability. Their frameworks advocate for equipping engineers with competencies to balance environmental, social, and economic priorities [8][9]. Yet, many programs continue to address sustainability superficially, treating it as an isolated concept rather than embedding it throughout the curriculum [2].

The EOP framework aims to address this gap by identifying learning outcomes for integrating sustainability into core engineering education. It focuses on systems thinking, environmental impact assessment, and responsible material selection, competencies vital for creating sustainable engineering solutions (Engineering for One Planet, 2020). These principles align with established sustainability frameworks like ISO 14040 for life-cycle assessment, which emphasizes evaluating environmental impacts across a product's lifecycle [10]. Systems thinking is critical for addressing the interconnected challenges of sustainability, enabling engineers to account for social, economic, and ecological systems in their designs [11][12].

In civil engineering, the integration of sustainability is especially urgent. The built environment contributes nearly 40% of global carbon emissions, with the construction industry driving significant resource use and waste generation (Global Alliance for Buildings and Construction, 2019). Sustainable building practices, including material selection, energy efficiency, and waste minimization, are essential for mitigating the sector's environmental impact [13][14]. However, achieving these goals requires a curriculum that emphasizes practical skills and systems thinking, which are often underrepresented in traditional programs [15].

Active and experiential learning approaches, such as project-based learning and reflective assignments, have demonstrated significant benefits in improving students' understanding of sustainability concepts and their application in professional contexts [16][17]. Frameworks like *How Learning Works* also highlight the importance of student motivation, prior knowledge, and mastery in achieving meaningful learning outcomes [18].

Building on this foundation, this study applies the EOP framework to the Sustainable Building Practices course, integrating EIA, MS, and ST. Through a combination of retrospective surveys and thematic analysis of photo-voice assignments, the research explores how this curriculum revision enhances students' ability to address sustainability challenges, offering a scalable model for engineering education.

3.0 Methodology

This study employed a mixed-methods approach to evaluate the integration of the EOP framework into the Sustainable Building Practices course. Quantitative retrospective surveys were used to measure changes in student learning outcomes, while qualitative photo-voice assignments explored students' experiences and perceptions. Twelve students were enrolled in the course, with eight voluntarily participating in the research components. Open-ended questions in the qualitative component provided deeper insights into how students perceived the course, including areas for improvement, essential sustainability skills, and advice for future participants. This design balanced quantitative measures with contextual qualitative data to comprehensively evaluate the curriculum's effectiveness.

Quantitative Retrospective Surveys

The questions were designed to evaluate students' understanding of the key learning outcomes associated with the three EOP framework topics: EIA, MS, and ST. The surveys assessed students' perceived proficiency both before and after the course. To measure self-reported learning gains, a Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree") was employed. This scale was tailored to capture the extent of students' agreement with statements regarding their knowledge and skills in sustainability concepts. A score of 1 indicated strong disagreement, reflecting that the student perceived minimal proficiency in the topic, while a score of 5 indicated strong agreement, indicating high proficiency in the learning outcome. The survey specifically focused on the following learning outcomes:

Table 1. The EOP topics and the core learning outcomes chosen for the course

EOP Topics	Learning Outcomes
Environmental Impact Assessment (EIA)	Core Outcome 1: I can explain the fundamentals of high-level environmental impact assessments, such as Life-Cycle Assessments (LCAs) and life-cycle hazards.
	Core Outcome 3: I am able to interpret the broader energy, climate, water, wastewater, air pollution, and land-use implications of my work through basic environmental impact assessments like LCAs and carbon footprints.
Materials Selection (MS)	Core Outcome 1: I understand the potential impacts of materials throughout the supply chain, from extraction through end of life, and can minimize negative impacts to the planet and its people.
	Core Outcome 6: I can select materials for design alternatives that ensure a long functional lifetime, minimal environmental and social harm, or contribute to a circular economy.
Systems Thinking (ST)	Core Outcome 1: I can explain the interconnectedness of systems, including the environmental and social impacts and consequences of human actions.

3.1 Qualitative Photo-Voice Assignments

Students completed photo-voice assignments as a reflective exercise. This involved capturing images that represented their understanding of sustainability concepts and providing written narratives to explain their choices. The prompts for the photo-voice assignments were based on the EOP topics covered in the course: one focused on EIA, another on MS, and a third on ST. This method encouraged active learning while serving as a qualitative data source for thematic analysis.

3.2 Curriculum Details and Key Assignments

The updated curriculum incorporated a variety of assignments and activities to align with the EOP framework and foster deep engagement with the topics of EIA, MS, and ST. A central component of the course was a comprehensive project in which students conducted a life-cycle assessment (LCA) of selected materials, evaluating their environmental impacts from extraction to disposal. Based on their findings, students identified sustainable alternatives and analyzed how their material choices influenced broader systems, including climate, energy, and resource cycles. This project encouraged students to apply systems thinking and make data-driven decisions about sustainable design. Additionally, students participated in interactive classwork, including group discussions and problem-solving exercises, where they analyzed case studies and collaborated on practical challenges. Photo-voice assignments were also integrated, allowing students to capture images and narratives reflecting their understanding of sustainability concepts. To further enhance their learning, the class visited the Ryan Resilience Lab, where they observed sustainable features and technologies in action, gaining firsthand insights into the practical application of sustainability principles. Educational videos and guided activities complemented these experiences, providing foundational knowledge on LCA methods, sustainable material selection, and the interconnectedness of systems.

3.3 Procedure

At the start of the course, students were introduced to the study and invited to participate voluntarily. Throughout the term, they completed photo-voice assignments aligned with the EOP topics of EIA, MS, and ST, which were collected and anonymized for thematic analysis. At the end of the course, retrospective surveys were administered to measure self-reported learning gains in alignment with the EOP framework topics. A final debrief session provided students an opportunity to share their perspectives on the curriculum changes and the value of sustainability-focused activities.

3.4 Data Analysis

Survey data were analyzed using descriptive statistics to calculate the mean and standard deviation of students' self-reported proficiency levels both before and after the course. The percentage change for each EOP topic was computed to quantify improvements in learning outcomes. For the qualitative component, thematic analysis was applied to the photo-voice assignments, guided by the *How Learning Works* framework. This framework, which emphasizes motivation, prior knowledge, and mastery, informed the identification of three key themes: Recognizing Value, Supportive Environment, and Student Efficacy. To ensure consistency and depth of interpretation, data were coded manually, with recurring patterns and insights synthesized into the thematic findings. The mixed-methods design was chosen to balance the depth and breadth of insights. Quantitative surveys provided a structured measure of learning gains, while qualitative photo-voice assignments captured contextual data on students' experiences. To ensure validity, survey questions were reviewed by another engineering technology faculty. Anonymization of photo-voice data and independent coding by the two researchers enhanced reliability and minimized bias during thematic analysis.

4.0 Results

4.1 Quantitative Results

The retrospective survey results, as illustrated in Figure 1, demonstrate significant improvements in students' self-reported proficiency across all EOP learning outcomes after completing the Sustainable Building Practices course. The surveys asked students to reflect on their understanding before and after the course. For EIA, students reported an increase in their ability to explain fundamental concepts (EIA: CO1) from a mean score of 2.33 before the course to 4.16 afterward, and an improvement in interpreting broader environmental implications (EIA: CO3) from 2.66 to 4.5. Similarly, for MS, students' understanding of material impacts across the supply chain (MS: CO1) increased from 2.83 to 4.5, and their ability to select sustainable materials (MS: CO6) rose from 2.5 to 4.5. Lastly, for ST: CO1, the students' ability to explain system interconnectedness improved from 3.0 to 4.5. These results highlight the effectiveness of the EOP framework in enhancing students' understanding and application of sustainability principles, aligning with the intended learning outcomes of the course.

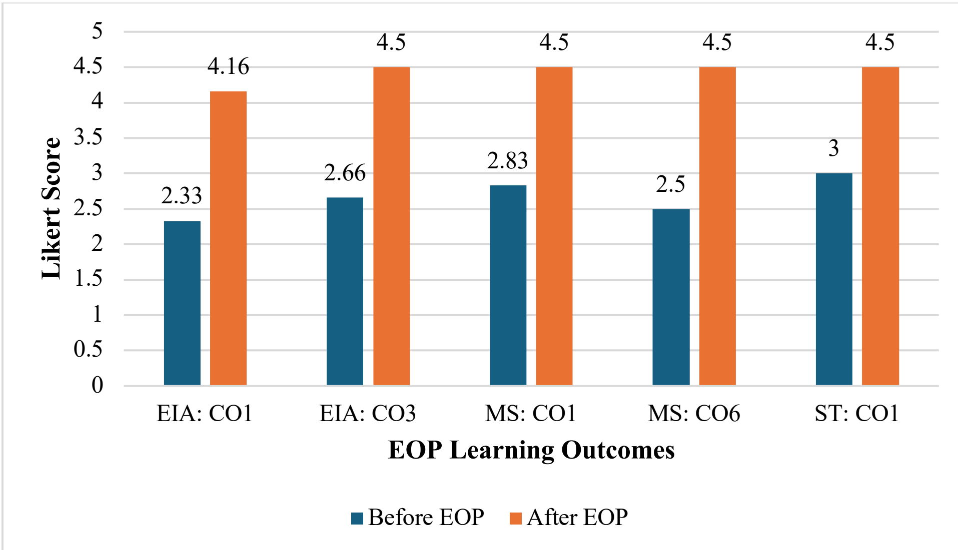

Figure 1. Comparison of students' self-reported proficiency in EOP learning outcomes (Environmental Impact Assessment (EIA), Materials Selection (MS), and Systems Thinking (ST)) before and after the course.

4.2 Qualitative Results

The qualitative analysis of the photo-voice assignments and open-ended survey responses revealed three overarching themes: Recognizing Value, Supportive Environment, and Student Efficacy. These themes, informed by the *How Learning Works* framework, highlight the depth of student engagement with the course material and their evolving understanding of sustainability principles.

Theme 1: Recognizing Value

Students frequently emphasized the importance of understanding sustainability principles within engineering contexts. One student highlighted the significance of systems thinking by stating, *"The Business Model Canvas is also a representation of how systems thinking is important to work environments. Without a Business Model Canvas, there would be no baseline for businesses to use, which would mean that businesses have no structure to work with."* Another student remarked on the broader impact of sustainable materials, noting, *"These materials help reduce energy consumption and maintenance costs, which helps promote positive cultural and environmental sustainability within the company."* Others reflected on the necessity of considering environmental impacts in project design, such as *"Understanding how a project's impact on the environment is crucial since protecting the environment means protecting where we live."* These reflections highlight how the course helped students see the practical and societal value of integrating sustainability into engineering projects.

Theme 2: Supportive Environment

The course fostered a supportive environment that enabled students to explore the tangible impacts of their design choices. One student shared, *"It helped me realize how small choices like material selection can shape the environmental and cultural impact of a project."* The use of recycled materials and their role in reducing waste and supporting long-term sustainability goals was also a recurring theme, with one student stating, *"Using recycled materials supports the practice of waste reduction. While reducing the amount of waste in landfills, we are also promoting long-term sustainability goals."* Students also appreciated how sustainable materials could improve safety and efficiency in the workplace, as exemplified by this comment: *"Engineering employees out in* *the field will also be free of harmful chemicals because sustainable materials minimize exposure to hazardous substances."* The ability to connect material choices to practical benefits, such as reduced stress and improved productivity for construction workers, was another notable insight: *"Materials with favorable properties can make workflow easier, improving productivity. This creates an efficient balance not only on the designers but also the construction workers using materials that are lightweight, reducing stress."*

Theme 3: Student Efficacy
Students reported a significant increase in their confidence and ability to apply sustainability-focused thinking in their projects. For instance, one student remarked, *"Using this style of thinking on different kinds of projects could help greatly improve in understanding relationships and interactions between the different parts, which could lead to a decrease in the time taken to complete a project."* Material selection emerged as a critical area where students felt empowered to make impactful decisions, as one student noted, *"Material selection in engineering plays a major role. Because materials impact a lot of aspects within engineering projects and the workplace, such as the efficiency, the sustainability, and even the durability."* Other reflections highlighted the broader implications of sustainable practices, such as conserving natural resources for future generations: *"By preventing as much environmental damage as possible, we could slow down the consummation of our natural resources and let the earth flourish more so that we have a steady stream of resources for future generations."* The importance of project planning and risk mitigation strategies was also noted: *"With good project planning it can directly tie into developing strategies for mitigating risks."*

Word Cloud
The word cloud generated from the students' responses to the open-ended questions (Figure 2) provides a visual representation of the concepts and themes emphasized by the students during the course. The open-ended questions that guided the students' reflections were: *"What aspect of this class helped you understand the role of engineers in ensuring solutions are sustainable long-term?"* and *"Which sustainability skills or practices do you think are most essential for engineers entering today's workforce?"*

Prominent words like "sustainable," "life," "materials," "important," and "projects" indicate a clear focus on sustainability principles. The repeated mention of "sustainable" reflects students' recognition of its importance in addressing long-term environmental challenges. Similarly, terms such as "materials," "energy," and "impacts" align with the course's focus on life-cycle considerations, particularly within the EIA and MS topics. The inclusion of terms like "activities," "hands," and "decisions" highlights the emphasis on active and practical learning exercises, while words like "systems," "thinking," and "technologies" resonate with the ST component of the curriculum. These findings suggest that students engaged deeply with the course topics and recognized their relevance to real-world engineering challenges.

Figure 2. Word cloud from students' responses, highlighting key concepts like sustainability, materials, and systems thinking.

5.0 Discussion

The results of this study indicate that integrating the EOP framework into the Sustainable Building Practices course enhanced students' understanding and application of sustainability principles in civil engineering. The quantitative and qualitative findings collectively demonstrate the impact of the revised curriculum on improving learning outcomes, improving students' critical thinking, and empowering them to approach engineering challenges with a sustainability mindset.

Regarding the quantitative findings, the survey results show significant improvements in students' self-reported proficiency across all EOP learning outcomes. For instance, the ability to explain the fundamentals of EIA: CO1 increased from 2.33 to 4.16, and the understanding of broader environmental implications, EIA: CO3 rose from 2.66 to 4.5. Similar gains were observed in MS and ST, with proficiency scores consistently improving to levels indicating confidence and mastery. These results suggest that the course succeeded in equipping students with the skills to analyze life-cycle impacts, make informed material choices, and evaluate the interconnectedness of systems. The substantial improvements across all topics affirm the effectiveness of the EOP framework in addressing the identified gaps in sustainability education.

Regarding the qualitative findings, the thematic analysis of the photo-voice assignments identified three key themes: Recognizing Value, Supportive Environment, and Student Efficacy. Students emphasized the importance of systems thinking and the role of sustainable materials in reducing environmental impacts and promoting long-term solutions. For example, students highlighted the value of frameworks like the Business Model Canvas in structuring sustainability-focused decisions and the role of recycled materials in fostering waste reduction and workplace safety. The theme of Supportive Environment highlighted the course's emphasis on hands-on learning and the importance of material choices in shaping environmental and cultural outcomes. Students appreciated how sustainable materials improved efficiency and minimized exposure to hazardous substances, enhancing both project quality and worker safety. Additionally, the theme of Student Efficacy demonstrates the course's success in building students' confidence to apply sustainability concepts in diverse contexts. Students reflected on the interconnected nature of systems, the role of planning in risk mitigation, and the importance of material durability, illustrating a sophisticated understanding of the principles taught. These reflections highlight the practical relevance of the EOP topics and their alignment with real-world engineering challenges [19,20,21].

The word cloud, generated from the students' responses to the open-ended questions, provides a visual synthesis of students' engagement with key sustainability concepts. The prominence of words like "sustainable," "materials," and "life" highlights the students' ability to connect course content to broader environmental challenges and long-term solutions. This suggests that the EIA and MS components were particularly effective in helping students understand the life cycle impacts of engineering decisions. Moreover, the emphasis on terms like "activities" and "hands" in the word cloud reflects the value students placed on the course's hands-on learning approach. This aligns with educational research showing that active learning enhances student engagement and understanding of complex topics, such as sustainability [22,23]. The recognition of terms like "systems" and "thinking" further demonstrates the impact of the ST module, as students acknowledged the interconnectedness of environmental, social, and technological systems [24]. The responses also indicate that students gained confidence in applying sustainability concepts to their future careers, as evidenced by the inclusion of terms such as "quality," "improve," and "details." These findings align with the qualitative themes identified, such as Recognizing Value and Student Efficacy, reinforcing that the course effectively bridged theoretical knowledge with practical applications.

From an instructor's perspective, several key lessons emerged during the course. The comprehensive LCA project engaged students effectively, but future iterations could include step-by-step guides, example case studies, and peer-review sessions to enhance understanding and collaboration. The field trip to a sustainable building proved highly impactful, and adding more real-world experiences like site visits or guest lectures would further enrich the curriculum. Mid-semester, adjustments such as providing additional guidance for photo-voice assignments improved student reflections, highlighting the importance of flexibility in course design. To enhance scalability, integrating peer reviews or streamlining project assessments could help manage workload without compromising learning outcomes.

While the findings are promising, the study has several limitations that should be addressed in future research. The small sample size restricts the generalizability of the results, though it still offers valuable insights into the course's effectiveness. To validate these findings and examine potential variations in outcomes, future studies could involve larger, more diverse cohorts. Moreover, incorporating longitudinal studies would provide a deeper understanding of how well students retain and apply sustainability concepts over time, particularly in their professional careers. Such studies could also include pre- and post-exam questions, providing more direct quantitative assessments of the curriculum's impact [25].

6.0 Conclusion

This study demonstrates the effectiveness of embedding the EOP framework into the Sustainable Building Practices course to enhance students' understanding and application of sustainability principles in civil engineering. The integration of EIA, MS, and ST into the curriculum significantly improved students' self-reported proficiency in sustainability-related skills, as evidenced by both quantitative and qualitative findings.

The results revealed substantial improvements in students' ability to assess environmental impacts, evaluate material choices, and understand systems interconnections. These gains highlight the importance of aligning sustainability instruction with real-world engineering practice. The qualitative analysis further highlighted how the course created a deeper recognition of sustainability's value, created a supportive learning environment, and empowered students to apply sustainability principles confidently in engineering contexts. By encouraging reflective and hands-on learning through photo-voice assignments and open-ended discussions, the course bridged theoretical concepts with practical applications.

Overall, this study provides a replicable model for integrating sustainability into engineering curricula, demonstrating how the EOP framework can prepare students to address the complex environmental and social challenges of their careers. By equipping future engineers with the knowledge and skills to make informed, sustainable decisions, this approach contributes to a more resilient and sustainable built environment. This approach contributes to a broader vision of engineering education that prioritizes sustainability as a core competency.

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