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Enhancing Sustainability Literacy in Engineering Education: Insights from Implementing the Engineering for One Planet Framework

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Sustainable development is no longer an option – it is a necessity. The availability and diversity of natural resources are increasingly threatened due to population growth, overconsumption, and climate change. These global impacts compel urgent action to mitigate adverse effects, adapt, and safeguard our future. Traditional engineering curricula have not sufficiently equipped students to address sustainability challenges. To bridge this gap, it is essential to integrate effective strategies and tools that strengthen sustainability concepts in engineering education. This study examines sustainability literacy among engineering students and evaluates the impact of targeted sustainability education in preparing them to tackle critical sustainability issues in industry, society, and the built environment. Specifically, the Engineering for One Planet (EOP) framework was introduced and implemented in two higher education institutions' civil engineering technology, construction management, and environmental sustainability curricula. Through pre- and post-course assessments of students' awareness and applications of sustainability concepts, we investigated the implementation of the EOP framework in fostering sustainability literacy among students in civil and environmental engineering-related programs based on initial implementation in nine courses reaching 272 students. 142 complete paired pre- and post-course responses were collected from the survey participants in eight of the courses. Descriptive statistics and the Wilcoxon Signed-Rank Test was used for the analysis. Preliminary findings suggest that students exhibit an improved understanding of sustainability concepts and feel more empowered to address sustainability challenges following explicit exposure to coursework aligned with the EOP framework. The findings from this study will guide engineering educators and stakeholders seeking to integrate sustainability principles into their curriculum. Instructors can better prepare future engineers to lead the charge in creating a more sustainable and resilient world by enhancing sustainability education in engineering courses.

1 Introduction

Sustainability is emerging as a cornerstone of modern education, particularly in engineering and related disciplines. The increasing complexity of global challenges—including climate change, resource depletion, and social inequality—demands a workforce equipped with the competencies to address these pressing issues. Higher education institutions are critical in shaping future leaders who can integrate sustainable practices into their professional and personal lives. As noted in a recent study, sustainability curriculum development has significant implications for enhancing students' learning experiences and employability, while also facilitating global comparisons of sustainability programs [1], [2]. However, integrating sustainability holistically into existing curricula remains a challenge, with educators and administrators often struggling to achieve collective curriculum integration [3], [4].

The urgency to integrate sustainability into higher education is underscored by the growing importance of the United Nations Sustainable Development Goals (SDGs), including embedded education-related targets. Incorporating the SDGs into curricula provides a compelling context for education for sustainable development (ESD) and supports the development of sustainability competencies that extend beyond technical knowledge to include cognitive and behavioral aspects of decision-making [5], [6]. Moreover, practical experiences are essential for equipping students with the competencies needed for sustainable problem-solving [7]. These experiential learning opportunities not only enhance technical skills but also inspire innovation and leadership, as demonstrated in programs that integrate hands-on and cooperative learning strategies [8], [9].

This study explores enhancing sustainability literacy in students in civil engineering technology, construction management, and environmental sustainability and the impacts of exposure to sustainability education geared toward preparing them to address pressing sustainability-related issues in industry, society, and the built environment. This study is based on the implementation of the Engineering for One Planet (EOP) framework to enhance sustainability literacy among these students based on initial implementation in nine courses at two universities in the U.S., reaching 272 students.

2 Background

2.1 The Need for Sustainability for the Future Workforce

As the global economy transitions towards more sustainable practices, the demand for professionals skilled in sustainability has grown exponentially. Universities are uniquely positioned to serve as models for sustainable development, fostering a multidisciplinary approach to education that emphasizes equity, justice, and environmental sustainability [10], [11]. The integration of sustainability into curricula can significantly enhance student engagement and awareness of environmental, economic, and social issues, equipping graduates with the skills and attitudes necessary to tackle complex global challenges [12].

One of the primary benefits of sustainability education is its ability to prepare students for the workforce by enhancing their employability and adaptability. Studies have shown that integrating sustainability principles into engineering education fosters critical thinking, problem-solving, and leadership skills [13], [14]. Additionally, education for sustainable entrepreneurship has been found to influence students' attitudes and propensity to act sustainably, although its direct impact on entrepreneurial intention remains limited [15]. This highlights the importance of coupling systemic knowledge with personal transformative learning to create a balanced and impactful educational experience [16] and to equip the future workforce with the skill sets and mindsets needed for sustainable development.

Despite these benefits, there are significant gaps and challenges in the implementation of sustainability programs, particularly at the undergraduate level. A study at the University of Washington suggested that most engineering programs don't prepare students to "engineer within the bounds of sustainability" (pg1), and that there is a need for more emphasis on the social and economic impacts of engineering in the curriculum and on building students' skills to address 21st century challenges that engineers will face [17] . Addressing these gaps requires immediate action to implement sustainable technologies and foster multidisciplinary research and public engagement [18]. Moreover, universities must develop tools for assessing learning outcomes related to sustainability, enabling educators to critically evaluate the effectiveness of their programs [13].

The future workforce must not only possess technical expertise but also the ability to connect ethical theories with engineering practices. An ethics-of-care approach, for instance, can enhance student understanding of sustainability by encouraging them to consider the broader social and environmental implications of their work [19]. By embedding these competencies into curricula, higher education institutions can ensure that their graduates are well-equipped to drive sustainable development in their respective fields.

2.2 Sustainability in Curricula in Civil Engineering and Related Disciplines

Civil engineering, as a discipline, is uniquely positioned to contribute to global sustainability efforts due to its direct impact on infrastructure development and resource utilization. However, the integration of sustainability into civil engineering curricula remains inconsistent, with a significant gap between theoretical aspirations and practical applications [20]. Recent studies highlight the necessity of evolving engineering curricula to emphasize lifelong learning, critical thinking, and integrating sustainability principles in problem-solving and decision-making [21], [22], [23]. This evolution is essential for fostering engineers who can serve as change agents in society [24].

Key challenges for curricular change in engineering programs include faculty and administrator concerns about how and where to include sustainability content in courses and programs that are already loaded to capacity, as well as a lack of confidence about teaching sustainability principles [25]. Another challenge is the lack of consensus on assessment methods and benchmarks [26]. Horizontal integration of sustainability concepts across curricula, as opposed to vertical integration in a single sustainability-focused course, has been shown to result in a more balanced understanding of sustainability, particularly regarding its social aspects [22], [27].

Higher education institutions must also address barriers to sustainable design and curricula delivery. These include a lack of decision-support systems tailored to real-world case studies and the predominance of environmental over social and economic considerations in higher education sustainability initiatives [28], [29]. Addressing these barriers requires a comprehensive understanding of sustainability that connects theoretical knowledge with practical applications [20].

Despite these challenges, there are promising developments in the field. For instance, the integration of social sustainability into curricula has been shown to improve students' understanding of community-centered design, enhancing their ability to create innovative solutions that address local needs [30]. Additionally, hands-on, experiential learning opportunities, such as those provided by international collaborative projects, significantly contribute to student learning and awareness of social impact [9]. These approaches enhance technical competencies and inspire a sense of responsibility and leadership among students.

To ensure the effectiveness of sustainability education in civil engineering, institutions must adopt a multidisciplinary approach that incorporates ethical considerations, public policies, and inclusive research methodologies [11], [31]. By doing so, they can prepare future engineers to address the complex challenges of sustainable development while fostering a culture of innovation and collaboration.

3 Methodology

3.1 Study Design

This study adopted a quantitative approach involving paired pre- and post-course survey data to evaluate the impact of implementing the EOP framework to enhance sustainability literacy among engineering students. The research assessed students' awareness, understanding, and application of sustainability concepts before and after exposure to EOP-aligned coursework.

The study was conducted across two higher education institutions offering programs in civil engineering technology, construction management, and environmental health and safety and aims to enhance environmental and social sustainability in the skillset of engineering and engineering technology students, using the EOP framework. Nine courses with a total enrollment of 272 were selected to implement the EOP framework learning objectives, designed to enhance students' knowledge, abilities, and skills in sustainability. All the courses had one instructor except for Introduction to Civil Engineering that had two instructors covering two sections. The survey received complete pre- and post- responses from 142 students enrolled in eight of those courses as listed in Table 1.

Table 1: Participant Academic Demographics

Variable	Category	N	Proportion of Responses (%)	Response Rate (%)
Institution	Institution 1	114	80.3	
	Institution 2	28	19.7	
Major	Civil engineering technology	102	71.8	
	Environmental sustainability health and safety	5	3.5	
	Environmental health and safety management	3	2.1	
	Construction management	18	12.7	
	Other	14	9.9	
Year (Academic Level)	First	61	43	
	Second	38	26.8	
	Third	21	14.8	
	Fourth	12	8.5	
	Fifth	5	3.5	
	Graduate	3	2.1	
	Other	2	1.4	
Course	Introduction to civil engineering	61	43	75.3
	Strength of materials	25	17.6	83.3
	Structural analysis and modeling	4	2.8	16.7
	Construction planning scheduling and control	16	11.3	94.1
	Principles of environmental sustainability health and safety	4	2.8	26.7
	Environmental health and safety management	4	2.8	26.7
	Construction materials and basic building systems	22	15.5	33.3
	Construction documents	6	4.2	31.6

The EOP Framework integrates sustainability principles into civil engineering and construction education, equipping future professionals with the skills and mindset to design and build systems that minimize environmental impacts, promote resilience, and create long-term value for society and the planet [32]. The EOP framework and supporting resources provided guidance on integrating sustainability concepts into course learning objectives, instructional materials, and assessments. The students enrolled in these courses are expected to gain more understanding of how engineers and professionals in related fields can serve as responsible stewards in their future roles in the industry based on the implementation of sustainability-focused course interventions using the EOP framework. This study focused on evaluating the outcomes of these courses through pre- and post-course assessments, which were administered to undergraduate and graduate students during the fall 2024 semester.

3.2. Participants

The participants included 142 undergraduate and graduate students enrolled in the selected courses (Table 1). These students were diverse in their academic backgrounds but shared a focus on engineering and environmental sustainability. Inclusion in this study was contingent upon completing the pre- and post-course surveys. To ensure ethical compliance, all participants were provided with an informed consent at the beginning of the survey and were assured of their confidentiality and voluntary participation rights. The study followed institutional research ethics board guidelines to maintain integrity and protect students' rights as research participants.

3.3. Course Interventions

Although instructors took different approaches to designing and applying the sustainability-related course interventions, all courses included in the study followed the same approach of mapping the course learning outcomes to the EOP learning outcomes. Modifications were made to the course content and assessments to better align with the focus on sustainability. Some interventions were broader covering several topics within the course while others were more focused and implemented one intervention covering one class session. A sample activity that was developed as one of the course interventions for ESHS 150 is presented below. This activity covered one class session. To begin, the relevant course learning outcome was mapped to one of the core EOP learning outcomes on social responsibility and the ABET student outcome 2 (Table 2). The sample activity developed for this intervention is shown in (Figure 1).

Table 2: ESHS 150 Sample Mapping of Learning Outcomes

Course Learning Outcome	**EOP Learning Outcome**	**ABET Student Outcome**
Recognize global EHS challenges and concerns with respect to energy and natural resource use, pollution, social justice, and sustainable development; and distinguish between sustainable and non-sustainable approaches and solutions.	SR.C.1.- Identify the United Nations Sustainable Development Goals (SDGs)	2- an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.

UN Sustainable Development Goals Activity – 100 Level

Activity: have students select an SDG to research, or randomly assign them, e.g., using a number draw. Use a think-pair-share approach to review and discuss all 17 of the SDGs.

Themes: sustainable development, UN SDGs, interconnectedness, problem-solving.

At the start of the class, provide an overview of the UNDP, background on the SDGs and how they are structured with targets and indicators. Briefly introduce the 17 goals, before assigning them to students.

In-class or out of class assignment:

1. Working in pairs, prepare a presentation with the following.
    a. Summary of your assigned goal(s)
        i. Short description/background
        ii. targets & indicators (top 3-4 is OK)
        iii. Summarize progress in US (to what extent is your goal/targets being tracked/what is the status of progress?)
2. Present to class as a "lightning" talk (5 min or less per goal)
3. In class discussion or take home assignment:
    a. what connections do you see among the goals and their targets?
    b. Characterize each goal – is it more of a social, environmental, or economic goal, or does it touch on more than one dimension? If the goal is oriented toward a single dimension (social, environmental, economic), what connections can you see to the other dimensions of sustainability?
    c. What do you see as barriers toward achieving these goals? What opportunities could be leveraged in support of the goals?
4. Optional follow-up: have students work in teams to play the Go Goals! game. https://go-goals.org/

Assessment:

Criteria	Weight	% Demonstrated
Engagement in class activity and presentation	20	
Accurate characterization of the goal, with clear, concise, but comprehensive presentation to class	60	
Able to discuss assigned goal and make connections to other goals	20	

Figure 1: Sample Course Intervention for ESHS 150

3.4. Data Collection

Quantitative data were gathered through surveys administered at the beginning and end of the semester through Qualtrics, an online survey development platform. These surveys assessed students' sustainability literacy using a combination of Likert-scale items and other multiple choice question types. Survey questions evaluated the awareness of sustainability concepts, confidence in addressing sustainability-related challenges, and interest in sustainability. All data presented were collected in Fall 2024. Only the 100% complete paired pre- and post-course responses were included in this analysis. The data were analyzed using IBM SPSS Statistics Version 29. Pre- and post-course survey data for the following variables were analyzed:

- Familiarity with the concept of sustainability
- Perception of the importance of sustainability in engineering and related fields
- Confidence in applying sustainability principles in their future professional work
- Understanding of economic, environmental, and social sustainability
- Interest in learning more about sustainability
- Likelihood of applying sustainability principles in their future careers

The exact phrasing of the questions included in the pre-course survey is provided below:

1) How familiar are you with the concept of sustainability?
    a) Not familiar at all
    b) Slightly familiar
    c) Familiar

    d) Extremely familiar
2) How important do you think sustainability is in the field of engineering and related fields?
    a) Not important at all
    b) Slightly important
    c) Important
    d) Extremely important
3) How confident are you in your ability to apply sustainability principles in your future professional work?
    a) Not confident at all
    b) Fairly confident
    c) Confident
    d) Extremely confident
4) Rate your current understanding of the following dimensions of sustainability in relation to this course:

	Excellent	Good	Fair	Poor
a) Economic sustainability	○	○	○	○
b) Environmental sustainability	○	○	○	○
c) Social sustainability	○	○	○	○

5) How interested are you in learning more about sustainability?
    a) Not interested at all
    b) Somewhat interested
    c) Interested
    d) Extremely interested
6) How likely are you to apply sustainability principles in your future career?
    a) Extremely unlikely
    b) Unlikely
    c) Likely
    d) Extremely likely

A variation of these questions was asked in the post-course survey. For example, on completion of this course, how familiar are you with the concept of sustainability? All the responses were based on a four-point Likert scale. The data were tested for normality using the Shapiro-Wilk test to assess the normality of pre- and post-course scores before conducting the paired analysis. All the pre- and post-course variables were non-normal since $P<0.001$, so a non-parametric test was used for the analysis.

4 Results

4.1 Familiarity with the concept of sustainability

A Wilcoxon Signed-Rank Test was conducted to evaluate the difference between pre- and post-course scores among 142 participants regarding their familiarity with the concept of sustainability before and after completing the course. The results indicated a statistically significant difference between the two conditions, $Z=6.760$, $p<0.001$, with a test statistic of 3678. This suggests that the intervention had a significant effect on the scores. The positive ranks exceeded negative ranks, indicating an improvement in scores after the intervention.

Students' responses were further analyzed by year (academic level). Generally, there was an improvement in the mean scores in the post-course scores compared to the pre-course scores for each of the students except for the fifth-year undergraduate students and students who identified as other where there was no change in the scores (Figure 2).

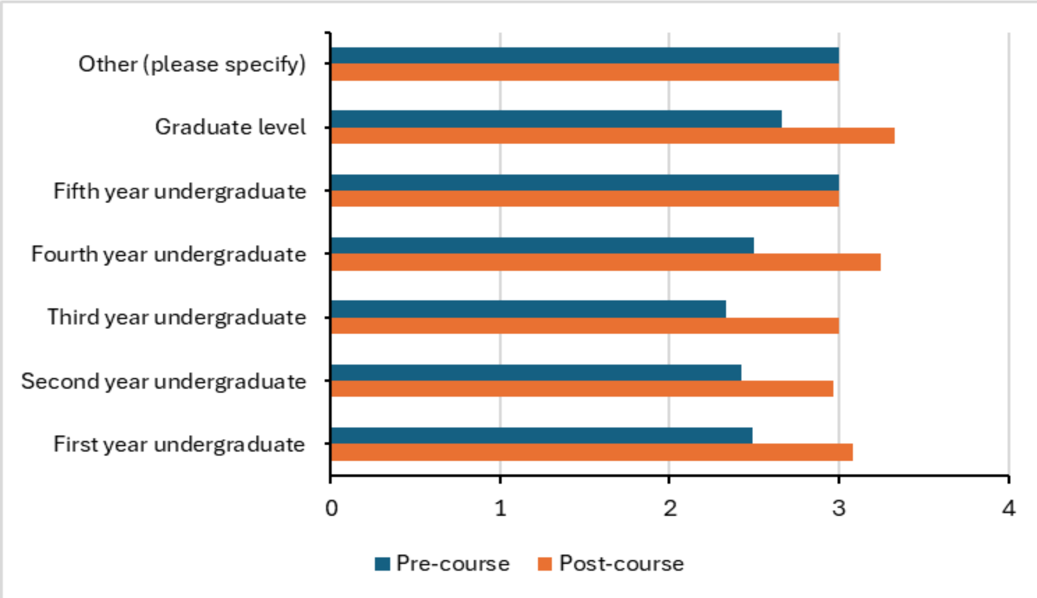

Figure 2: Comparison of mean scores on familiarity with the concept of sustainability

4.2 Perception of the importance of sustainability in engineering and related fields

In evaluating the difference in the pre- and post-course scores among the 142 participants, the Wilcoxon Signed-Rank Test showed no statistically significant difference between the pre- and post-course responses (Z=0.966, p=0.334, with a test statistic of 645). These findings suggest that the intervention did not result in a significant change in their perception of the importance of sustainability in engineering.

4.3 Confidence in applying sustainability principles in their future professional work

Results of the Wilcoxon Signed-Rank Test that was performed to compare pre- and post-intervention scores assessing participants' perceptions of sustainability and their self-reported confidence in applying sustainability principles in their future profession revealed a statistically significant increase in scores following the intervention, T=2782.000, Z=4.204, p<0.001. This indicates that the students exhibited a measurable improvement in their confidence in applying sustainability principles in their future professional work after exposure to the intervention.

4.4 Understanding of economic, environmental, and social sustainability

The Wilcoxon Signed-Rank Test evaluated participants' self-rated understanding of economic sustainability before and after completing the course. The results (T=4222.500, Z=7.682, p<0.001) show a statistically significant improvement in their understanding. This indicates that the course effectively enhanced participants' comprehension of economic sustainability concepts. In assessing participants' self-rated understanding of environmental sustainability before and after the course, the results (T=3483.000, Z=7.077, p<0.001) indicate a statistically significant increase in understanding. This suggests that the course successfully improved participants' understanding of environmental sustainability concepts. The Wilcoxon Signed-Rank Test assessed participants' self-rated understanding of social sustainability before and after the course. The results (T=4338.000, Z=7.344, p<0.001) indicate a statistically significant increase in understanding of social sustainability. This suggests that the course successfully improved participants' understanding of the economic, environmental, and social sustainability aspects.

Further, students' understanding of economic, environmental, and social sustainability were analyzed based on their indicated major (Figure 3). Except for the EHSM students, for the pre-course responses, students in other majors reported their understanding of environmental sustainability as the highest and their rating of the understanding of social sustainability was the lowest while EHSM students rated their understanding of the three aspects of sustainability the same. All the post-course mean scores were higher across the groups but a similar trend was observed where the post-course scores for environmental sustainability was the highest and the lowest was for social sustainability except for students in the ESHS major who rated their understanding of social sustainability higher than their understanding of economic sustainability.

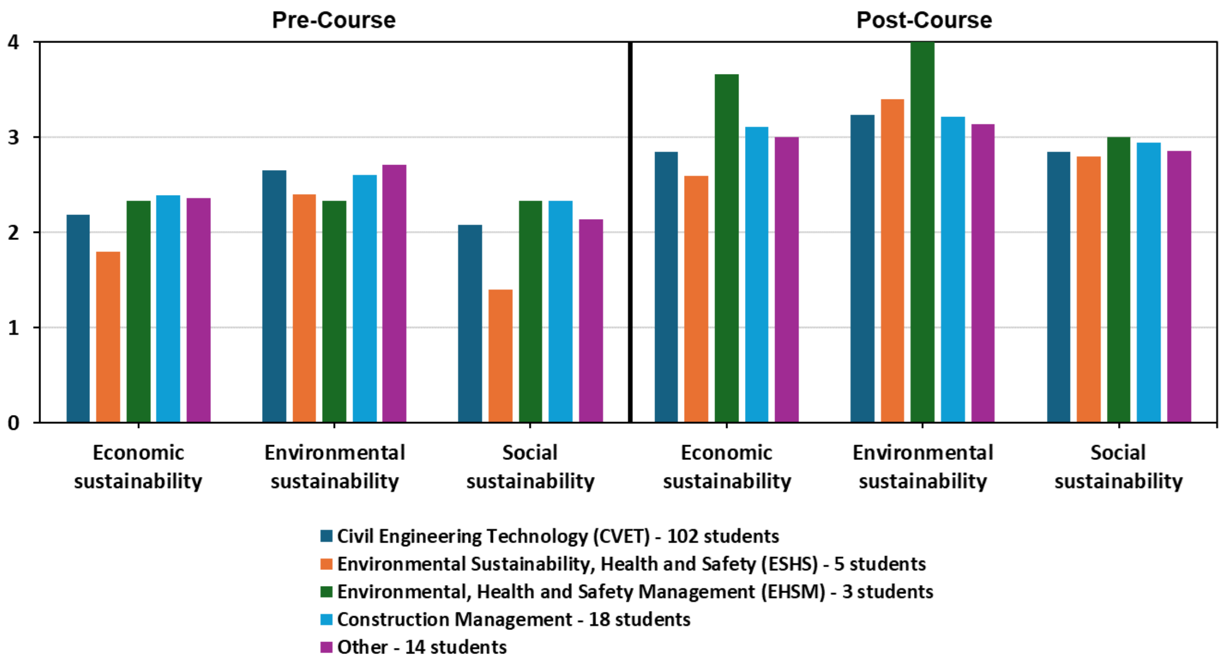

Figure 3: Comparison of student understanding of economic, environmental, and social sustainability

4.5 Interest in learning more about sustainability

The Wilcoxon Signed-Rank Test compared participants' interest in learning more about sustainability before and after exposure to course content. The results (T=691.000, Z=−3.661, p<0.001) indicate a statistically significant increase in interest following the course. This suggests that the course effectively heightened participants' enthusiasm for learning more about sustainability principles.

4.6 Likelihood of applying sustainability principles in their future careers

The Wilcoxon Signed-Rank Test compared participants' likelihood of applying sustainability principles in their future careers before and after exposure to course content. The results (T=500.000, Z=−1.511, p=0.131) indicated no statistically significant difference (p>0.05). This suggests that the course did not significantly influence participants' reported likelihood of applying sustainability principles in their future careers. Additional strategies may be needed to strengthen the impact of sustainability education on students’ future application intentions.

5 Discussion

The selected courses span two institutions and four different programs. The statistically significant improvement in participants' familiarity with sustainability concepts after completing the course demonstrates the effectiveness of the intervention in increasing baseline knowledge. Trends were similar between different programs, with small variations that can be attributed to the differences in the population sample. However, variations in mean scores by year suggest differential impacts, potentially influenced by varying levels of exposure or prior knowledge. Fifth-year and "other" students exhibited less improvement, potentially indicating a need for tailored approaches for the fifth-year students, even though the feedback could indicate a higher level of prior sustainability knowledge.

Contrary to expectations, no significant change was observed in participants' perceptions of the importance of sustainability in engineering and related fields. This finding suggests that while the course improved familiarity and understanding, it did not adequately challenge or expand students' pre-existing beliefs regarding the importance of sustainability. This may point to the need for integrating more real-world examples, case studies, or experiential learning activities to more effectively emphasize the critical role of sustainability in professional practice to impact the global future positively. However, this can also indicate that students have a high baseline for understanding the importance of sustainability due to prior exposure or other outside factors.

The significant increase in confidence to apply sustainability principles in future work highlights a key success of the course. Students' increased self-assurance shows the applied nature of the course content, which emphasized practical approaches to integrating sustainability in engineering contexts. This suggests that the course successfully equipped students with skills they could utilize in professional settings, although additional efforts could further solidify this confidence for broader application.

Considering the three sustainability dimensions, the course successfully improved students' self-rated understanding of all three dimensions. Environmental sustainability consistently received the highest ratings among students in all programs, while social sustainability was often rated the lowest, except among EHSM students who indicated a better understanding of social sustainability. This trend suggests that students may perceive environmental sustainability as more tangible or directly applicable, while social sustainability remains more abstract. Tailoring the curriculum to provide stronger examples and applications for social sustainability might help address this discrepancy. Additionally, demonstrating through specific examples the relationship between the three sustainability aspects, environmental, social, and economic, could also improve students’ understanding of how one aspect can quickly impact the other.

The significant increase in students' interest in learning more about sustainability principles indicates that the course was able to engage and inspire curiosity. This outcome is favorable, as it indicates that students are motivated to pursue further education or explore sustainability topics, which may translate into lifelong learning. This finding indirectly contradicts the lack of significant change observed in participants' perceptions of the importance of sustainability in engineering and related fields.

The lack of significant change in the likelihood of applying sustainability principles in future careers raises concerns about the long-term impact of the course. While the intervention enhanced confidence and understanding, these improvements did not translate into an increased intention to apply sustainability in practice. This suggests a gap between education and real-world applicability. Future iterations of the course will include hands-on projects and industry collaborations to reinforce the relevance of sustainability in professional contexts.

6 Conclusion

The EOP framework was implemented into nine courses in civil engineering, environmental sustainability, and construction management, reaching 272 students across two US universities. This study highlights the potential of sustainability-focused courses to enhance sustainability literacy by improving knowledge, confidence, and interest among engineering students. The course was particularly successful in improving students' familiarity with sustainability, understanding of economic, environmental, and social dimensions, and interest in sustainability topics. The results demonstrated an increase in sustainability literacy and emphasize the importance of continuous evaluation and adaptation of educational strategies to ensure that sustainability principles are effectively integrated into students' professional mindsets and practices. This will help cultivate a generation of engineers who are not only knowledgeable about sustainability but are also committed to applying these principles to create a more sustainable future.

The study has some limitations, including a lack of significant change in perceived importance and likelihood of applying sustainability in careers. Addressing these gaps through curriculum enhancements—such as case-based learning, project-based learning, experiential learning activities, and industry partnerships—could further strengthen the impact of sustainability education. In addition, the Likert scale survey results could be subjective when students evaluate themselves about understanding sustainability. Also, the survey response rates vary from 16.7% to 94.1% across the eight courses, which may not provide an opportunity to fully capture a representative sample for courses with low response rates.

Future work includes the implementation of course interventions in additional courses in the spring semester and an iterative improvement of the interventions yearly based on faculty peer and student feedback. Interviews will also be conducted to gain deeper insights into the impact of the interventions on students' learning and application of sustainability concepts.

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