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Embedding Sustainability Concepts in an Introductory Civil Engineering Technology Course

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Incorporating sustainability concepts early and progressively in the civil engineering undergraduate curriculum is crucial to preparing students for the complex infrastructure challenges the modern construction industry faces. Early sustainability-focused interventions in the curriculum can facilitate the dissemination of more advanced sustainability concepts in later courses, thereby improving overall student outcomes. This study investigates the impact of sustainability-focused interventions on students' familiarity, confidence, and intention to apply sustainability principles in practice in a first-year civil engineering technology course at a private higher education institution. Guided by the Engineering for One Planet Framework, the course integrated sustainability concepts into course content, activities, and assessments. Pre- and post-course survey responses were analyzed using the Wilcoxon signed-rank test to assess changes in selected variables following the intervention. Among the variables analyzed, students showed the greatest overall improvement in understanding the economic sustainability dimension. There was a 16% improvement in students' confidence in applying sustainability in practice, although their perceived likelihood of future application remained steady. This study contributes to the development of evidence-based strategies to introduce sustainability into civil engineering courses, thereby preparing a future workforce capable of delivering sustainable solutions in the built environment.

Keywords: Civil Engineering, Engineering Education, Sustainability-focused Curriculum, Engineering for One Planet, Sustainability Integration

Introduction

The civil engineering and construction industries are critical to achieving sustainable development. Goubran's (2019) research on the relationship of construction and related sub-sectors to the United Nations' (UN) 2030 Agenda for Sustainable Development maintains that 44% of the specific targets across all 17 of the UN Sustainable Development Goals (SDGs) are influenced by the construction sector, thus highlighting the vital role it plays. However, there are significant gaps in the sustainability expertise of professionals in these industries (Sandanayake et al., 2022). The 2024 LinkedIn Global Green Skills Report indicates that the construction industry ranked second in demand for green skills, with 20.6% of job postings requiring skills related to combating the effects of climate change, emphasizing the urgent need for experts proficient in environmentally sustainable construction practices (LinkedIn, 2024).

Integrating sustainability into civil engineering and construction curricula would nurture the next generation of professionals who can adapt to the global economy's increasing focus on green practices (Farnsworth et al., 2024; Barbosa Júnior et al., 2023). Approximately 20 years ago, sustainability was not a standard requirement in the curricula of civil engineering undergraduate programs (Russell & Stouffer, 2005); however, in recent years, sustainability has evolved from an industry-specific focus to an educational imperative, leading many programs to incorporate sustainability-focused modules and courses into the curriculum (Sisiopiku et al., 2015).

This study evaluated the effectiveness of sustainability-focused curricular interventions guided by the Engineering for One Planet (EOP) framework in a first-year civil engineering technology undergraduate course at a large private Higher Education Institution (HEI). It builds on the growing body of literature emphasizing the importance of sustainability in engineering education. Specifically, it builds upon previous work by Abraham & Bao (2023), who piloted sustainability-focused interventions in an introductory civil engineering course in the Fall 2022 semester. The interventions were modified for the Fall 2024 cohort to continually improve students' sustainability learning outcomes. The overarching curricular goal was to establish a strong foundational understanding of sustainability that could be progressively reinforced across subsequent courses in the civil engineering technology program. The objectives of this study were to examine changes in students' familiarity with and understanding of sustainability concepts, assess their confidence and preparedness to apply sustainability principles in practice, evaluate interest and intention to engage with sustainability in future careers, and gauge perceptions of the effectiveness of instructional methods and course-level sustainability integration. The findings inform iterative curriculum refinement and support the progressive integration of sustainability across the undergraduate civil engineering curriculum.

Integration of Sustainability in Civil Engineering Education

A study by Farnsworth et al. (2024) examined 307 civil engineering and construction-focused undergraduate programs in the United States and found that approximately two-thirds had adopted a sustainability-centered curriculum. This emphasizes the growing academic interest in incorporating sustainability into civil engineering and construction education. While integrating sustainability into HEIs has become a global priority, advancing its integration across course levels remains a challenge. Engineering programs traditionally emphasize technical content, often overlooking sustainability (Gutiérrez-Bucheli et al., 2023). As such, it is expedient that the civil engineering curriculum in HEIs follows a progressive pattern of systematically incorporating sustainability education into courses rather than focusing such interventions solely on upper-level curricula. (Desha et al., 2009). A study by Mares-Nasarre et al. (2023) showed that most civil engineering students reach the third year of the program without a comprehensive understanding of sustainability concepts. This reveals the existing gap in sustainability-focused intervention in the curriculum across consecutive academic levels. Embedding sustainability concepts early on in civil engineering curricula offers an opportunity to reinforce learning and build on previously mastered concepts in subsequent courses, ultimately improving students' understanding of sustainability over time (Gutierrez-Bucheli et al., 2023).

Several studies have demonstrated the pedagogical value of introducing sustainability concepts early in civil engineering curricula. Ozis et al. (2022) implemented a tangram activity at three HEIs to improve engineering students' perception of sustainable design. Their results indicated significant improvement in first-year students' understanding of sustainability and its connection to innovation and engineering, regardless of major, instructor, or institution. In a study by Vaez Ghaemi et al. (2024), first-year students who participated in sustainable design activities reported stronger innovation-oriented mindsets, suggesting long-term benefits from early exposure. Tisdale et al. (2022) reported that first-year civil engineering students' comprehension of sustainability improved

significantly, although their confidence in applying these concepts remained limited, highlighting a gap between theoretical understanding and practical application. While students may understand the importance of sustainability, they often lack the practical skills and competencies required to confidently incorporate these principles in professional practice (Vaez Ghaemi et al., 2024). Roure et al. (2018) introduced sustainable development through a streamlined Life Cycle Assessment (LCA) framework in a capstone project course for civil engineering students. Across three consecutive cohorts, there was a progressive improvement in students' performance, which the authors attribute primarily to prior LCA knowledge from other courses and to improved teaching methods.

With the growing institutional commitment to embedding sustainability in engineering education, the EOP framework provides a structured approach for integrating sustainability concepts into all engineering disciplines (The Lemelson Foundation, 2026). It is an actionable tool launched in 2020 and revised in 2025, with nine topics, each having core and advanced sustainability-focused learning outcomes that can assist educators in incorporating sustainability into engineering curriculum (The Lemelson Foundation, 2026). Using this framework, Abraham & Bao (2023) modified the existing curriculum to integrate sustainability into two civil engineering technology program courses, Introduction to Civil Engineering and Structural Steel Design, serving first-year and fourth-year students, respectively, in Fall 2022. Post-course survey results revealed that 80% of students had improved understanding of sustainability topics, and 90% demonstrated a better understanding of how they, as future civil engineers, can participate in efforts to build a sustainable environment. After revising the sustainability-focused interventions based on feedback from this pilot study, Bao et al. (2025) conducted a follow-up study involving students who took the structural steel design course in Fall 2023. The authors found that 91% of the students had an improved understanding of sustainability topics, and 95% demonstrated a better understanding of how they, as future engineers, can contribute to building a sustainable environment. Across these two cohorts, there was a 13.8% increase in the students' understanding of sustainability. These findings suggest that progressive modifications to sustainability-focused interventions can improve students' understanding of sustainability in the civil engineering curriculum. A subsequent study that included additional courses found that students demonstrated improved understanding of sustainability concepts and felt more empowered to address sustainability challenges after explicit exposure to coursework aligned with the EOP framework (Abraham et al., 2025).

A variety of pedagogical approaches have been used in teaching sustainability concepts within HEI curricula, including case studies, interdisciplinary team teaching, lecturing, mind/concept maps, and project-problem-based learning (Lozano et al., 2017). Chau (2007) employed a problem-based learning approach in a design project to help students develop practical expertise incorporating sustainability into engineering design. While numerous studies (Rose et al., 2015; Ozis et al., 2022; Vaez Ghaemi et al., 2024) have examined the outcomes of sustainability interventions among first-year civil engineering students, gaps remain, and additional analysis of student outcomes data is needed. Consequently, this study aims to contribute to the body of knowledge on integrating sustainability into engineering curricula by conducting a robust, systematic evaluation of first-year students' learning outcomes, attitudes, and intentions towards sustainability in their future careers.

Methodology

Introduction to Civil Engineering is one of the foundational courses offered to students enrolled in the Civil Engineering Technology program, a Bachelor of Science degree that advances students' ability to analyze, design, and build resilient infrastructure in the built environment. In the Fall of 2024, the course had a total enrollment of 81 students between two sections. Each section was taught by a different faculty member, who used the same materials and interventions in the course. This is one of

the department's courses that was modified to incorporate sustainability concepts through the research study. The study was approved by the Human Subjects Research Office at the Rochester Institute of Technology and adheres to the Research Ethics Board's guidelines to maintain integrity and protect the rights of research participants. The course learning outcomes, along with the relevant EOP learning outcomes, are listed below.

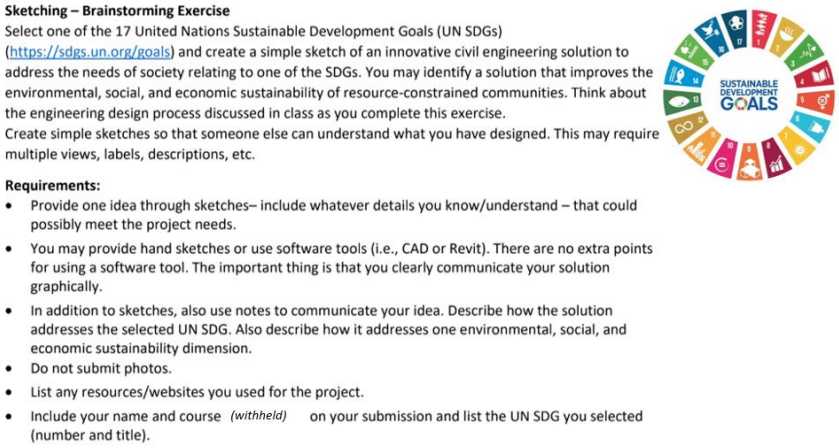
- Understand the fundamentals of civil engineering graphics (C&TW.C.1.)
- Create fundamental civil engineering graphics elements (ST.C.1. and C&TW.C.1.)
- Interpret construction drawings for different civil engineering disciplines (ST.C.1.)
- Distinguish different civil engineering disciplines and understand the basics of sustainable design (ST.C.1., ST.C.2. and SR.C.1.)
- Describe the importance of construction drawings (ST.C.1.)

Table 1 presents the mapping of EOP learning outcomes to their corresponding ABET outcomes.

Table 1. Relevant EOP learning outcomes and associated ABET outcomes

EOP Learning Outcome	Description	Associated ABET Outcomes
Systems Thinking Core Outcome 1 (ST.C.1)	Explain interconnectedness and how all human-made designs and activities rely upon and are embedded within ecological and social systems	4- Ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
Systems Thinking Core Outcome 2 (ST.C.2)	Identify dynamic impacts between and among different parts of the system (i.e., social, environmental, and economic considerations)	
Social Responsibility Core Outcome 1 (SR.C.1)	Identify the United Nations Sustainable Development Goals	2- Ability to design engineering solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
Communication & Teamwork Core Outcome 1 (C&TW.C.1)	Communicate through audience-specific written, graphic/ visual, oral, and interpersonal communication skills	3- Ability to communicate effectively with a range of audiences 5- Ability to function effectively with team members for leadership, collaboration/inclusion, setting goals/tasks and meeting objectives

Modifications were made to the course content and assessments to better align with the sustainability focus. The course also included guest lectures and site visits to help students understand and observe real-world applications of sustainability in the built environment. In addition, the students were introduced to the UN SDGs and the engineering design process, with emphasis on their relevance to civil engineering. For this topic, they completed a take-home assignment that was developed as one of the course interventions (Figure 1).



Sketching – Brainstorming Exercise

Select one of the 17 United Nations Sustainable Development Goals (UN SDGs) (https://sdgs.un.org/goals) and create a simple sketch of an innovative civil engineering solution to address the needs of society relating to one of the SDGs. You may identify a solution that improves the environmental, social, and economic sustainability of resource-constrained communities. Think about the engineering design process discussed in class as you complete this exercise.
Create simple sketches so that someone else can understand what you have designed. This may require multiple views, labels, descriptions, etc.

Requirements:

- Provide one idea through sketches– include whatever details you know/understand – that could possibly meet the project needs.
- You may provide hand sketches or use software tools (i.e., CAD or Revit). There are no extra points for using a software tool. The important thing is that you clearly communicate your solution graphically.
- In addition to sketches, also use notes to communicate your idea. Describe how the solution addresses the selected UN SDG. Also describe how it addresses one environmental, social, and economic sustainability dimension.
- Do not submit photos.
- List any resources/websites you used for the project.
- Include your name and course *(withheld)* on your submission and list the UN SDG you selected (number and title).

Figure 1. Sample sustainability-focused course intervention assignment aligned with the UN SDGs

To assess the impact of the course modifications, students were invited to complete a pre-course survey at the beginning of the semester. Upon exposure to the modified course materials, they completed a post-course survey (Table 2).

Table 2. Pre- and post-course survey questions

Question Focus	Pre/ Post	Response Type
Familiarity with sustainability concepts	Both	Likert scale (1–4)
Importance of sustainability in engineering and related fields	Both	
Confidence in applying sustainability principles in practice	Both	
Understanding of the economic, environmental, and social dimensions of sustainability	Both	
Exposure to sustainability concepts in previous courses	Pre	Likert scale (1–5)
Courses in which students were previously exposed to sustainability concepts	Pre	Open-ended
Interest in learning more about sustainability	Both	Likert scale (1–4)
Likelihood of applying sustainability principles in practice	Both	
Preparedness to address sustainability challenges in future practice	Post	Likert scale (1–5)
Teaching methods most helpful in understanding sustainability concepts	Post	Multiple select option
Effectiveness of sustainability integration in the course	Post	Likert scale (1–5)

The first section of the survey collected demographic information about the students, while the second section assessed their interest in, awareness of, and familiarity with sustainability-focused concepts. Given the increasingly nuanced nature of gender demographics, which may stir students' awareness of minorities and stereotypes, such questions were excluded from the survey. Similar questions were included in both the pre- and post-course surveys to facilitate comparisons. Each question was designed to examine a single underlying construct in measuring the student outcomes. The pre-course and post-course surveys were administered through the Qualtrics survey platform. Students were invited to scan the QR code and complete the online surveys during class. In both surveys, paired variables used the same Likert scale type to enable direct comparison of changes in students'

outcomes following the sustainability-focused interventions. The analysis of the collated data was conducted using IBM SPSS Statistics Version 30.0.0.0 (172). Before analyzing the data, participant IDs from both the pre-course and post-course surveys were matched to ensure accurate pairing. Incomplete survey responses were excluded, and only complete paired responses were analyzed.

Results and Discussion

Study Demographics

Eighty-one students enrolled in the Introduction to Civil Engineering course in Fall 2024 and 61 completed the pre- and post-course surveys, yielding a response rate of 75.3%. 93.4% of these were civil engineering majors and the remainder were engineering exploration students. The course was primarily taken by first-year students (91.8%); the remainder were second-year students who had transferred into the program from another institution or major. An examination of students' background knowledge of sustainability indicated that most had a stronger understanding of environmental sustainability than of economic and social sustainability before the course. Additionally, 31.1% of students reported never having been exposed to sustainability concepts in previous courses, while another 47.5% indicated they occasionally encountered them. Given this limited exposure and students' strong interest in sustainability, the interventions have significant potential to improve student outcomes. The common courses in which students reported being introduced to sustainability concepts included civil engineering, architecture, and principles of design. Furthermore, some students reported being exposed to sustainability in high school subjects such as engineering, chemistry, and environmental science. The recurrence of these course contexts suggests that the built environment and civil engineering fields provide a natural medium for integrating sustainability content into the curriculum, as they directly influence sustainable development.

Survey Findings

Each variable in both pre- and post-survey data was tested for normality, as assessing data normality is crucial for determining the appropriate parametric/nonparametric statistical test (Kuzon et al., 1996). Results showed that the data from both surveys did not follow a normal distribution; as a result, the Wilcoxon signed-rank test was used to analyze the survey data (pre- and post-course), and the results for the variables analyzed are presented in Table 3. The Mean Difference (M.D.), which measures the difference in mean scores between pre- and post-course survey responses, indicates whether the observed statistically significant difference is positive or negative. Although Wilcoxon signed-rank tests were conducted for all 8 variables, no correction for multiple comparisons was applied. Each variable had a distinct mean score after the intervention; consequently, the omnibus null hypothesis was rejected (Garcia-Perez, 2023).

Figure 2 presents a comparison of the mean scores between the pre-course and post-course surveys. There was a significant improvement in students' familiarity with sustainability concepts and confidence in applying them, suggesting the effectiveness of the interventions in increasing students' knowledge of sustainability and in building confidence in its application. The observed decrease in students' interest in learning more about sustainability after the course is concerning but may suggest that they found the course satisfactory, thereby reducing their motivation to learn further. This is corroborated by Di Domenico & Ryan (2017) and Murayama et al. (2019), who suggest that decreased motivation for learning may be linked to perceived competence/mastery and/or expectations being met. Since strong intention is an indicator of behavior (Conner & Norman, 2022), the decline in interest in learning about sustainability could pose challenges for students' future engagement with these topics. Increased motivation to learn more about sustainability, especially in a

first-year course, is crucial for fostering students' preparedness to study advanced sustainability concepts in later years of their program (Hidi & Renninger, 2006). The minimal decline in students' likelihood of applying the sustainability principles learned in practice highlights the need to develop more effective, sustainability-focused interventions that can influence this outcome. Moreover, it may be too early for students to understand in practical terms how they could contribute to advancing sustainability goals in professional settings (Vaez Ghaemi et al., 2024).

Table 3. Summary of Wilcoxon signed-rank test analysis of key paired variables

Variable analyzed	M.D. (%)	Statistics	Interpretation
Familiarity with sustainability	11.5	T=829, Z=-4.71, p<0.01	Statistically significant improvement
Importance of sustainability	2.7	T=103.5, Z=-1.177, p=0.239	No statistically significant change
Confidence in applying sustainability	16	T=157.5, Z=-3.677, p< .001	Statistically significant increase
Understanding of economic sustainability	38.1	T=35, Z=-5.582, p< .001	Statistically significant improvement
Understanding of environmental sustainability	23.1	T=90, Z=-4.42, p< 0.001	Statistically significant improvement
Understanding of social sustainability	27.3	T=84.5, Z=-4.431, p<0 .001	Statistically significant improvement
Interest in learning about sustainability	-14.3	T=131, Z=-5.62, p=0.004	Statistically significant decrease in interest
Likelihood to apply sustainability principles	-2.94	T=94.5, Z=-2.867, p=0.414	No statistically significant change

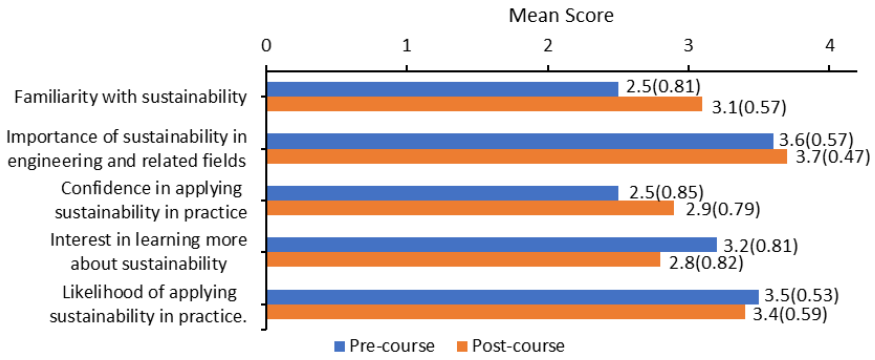


Figure 2. Mean scores and standard deviation from pre- and post-course survey Likert responses on sustainability competencies

Figure 3 compares the mean scores of students' understanding of sustainability dimensions. The 4-point Likert scale question addressing this in the survey was "Considering the topics you learned in this course, rate your current understanding of the following dimensions of sustainability." There were increases of 38%, 23%, and 27% in the economic, environmental, and social dimensions of sustainability. Comparatively, students demonstrated the greatest understanding of the environmental

domain both before and after taking the course, as indicated by the mean scores. This pattern, also found by other researchers, shows that environmental sustainability is the most familiar facet of sustainability among civil engineering students, even after sustainability-focused interventions (Dancz et al., 2017).

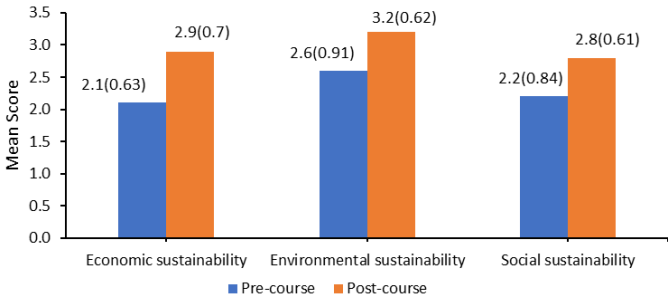


Figure 3. Mean scores and standard deviation from pre- and post-course survey responses on the students' understanding of sustainability dimensions

Furthermore, the Cronbach's alpha (α) for the questions assessing students' understanding of the sustainability dimensions was 0.739 for the pre-course and 0.754 for the post-course. Both values were acceptable in terms of internal consistency($\alpha>0.7$) as supported by Fellows and Liu (2015). This further reveals that the questions reliably measured the students' understanding of sustainability across its dimensions. Further reflective and future application feedback from the students showed that they moderately feel equipped (Mean score=3.3) to apply the knowledge they gained from the course in practice. Additionally, students indicated that the course prepared them "very well" (Mean score= 3.4) to address sustainability challenges in their future careers. They also found the sustainability-focused interventions effective (Mean score = 3.8) in incorporating sustainability into the curriculum. In response to the teaching methods that helped improve their understanding of sustainability concepts, lectures and hands-on learning were the most frequently selected.

Conclusion

This study examined the impact of sustainability-focused interventions in an introductory civil engineering technology course, highlighting how curriculum modifications can potentially enhance students' ability to apply sustainability principles in practice. Pre- and post-course surveys revealed significant improvements in students' understanding of the economic, environmental, and social dimensions of sustainability, as well as increased confidence in applying these concepts in practice. Although students' perceived likelihood of implementing sustainability principles did not change significantly, the findings emphasize the value of early and continuous exposure to sustainability throughout the program. Overall, the results demonstrate that a well-designed, sustainability-centered curriculum, supported by active learning strategies, can improve students' learning outcomes.

One limitation of this study is its reliance on self-reported data from a single institution, restricting its generalizability. Additionally, the sustainability-focused interventions in the first-year course did not sufficiently stimulate students' motivation for further learning; future modifications will aim to address this gap. Subsequent work will also explore longitudinal studies across multiple cohorts to examine additional metrics, such as assessment performance, and evaluate how early sustainability interventions influence students' professional identity in their future careers. The effects of pedagogical methods, instructors' proficiency in sustainability concepts, and other instructor-related factors can also be investigated to identify broader influences on intervention effectiveness. This study

contributes to the growing body of evidence supporting curriculum modifications in engineering education and informs scalable, evidence-based strategies to better prepare the next generation of civil engineers for a sustainable built environment.

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