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Implementing the Engineering for One Planet Framework in a Civil Engineering Technology Program

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Abstract

To address the challenges facing the built environment and promote sustainability, it is essential for the future engineering workforce to be well-equipped to design, construct, operate, and manage infrastructure projects and systems. Civil engineers play a vital role in this process by contributing their expertise to develop sustainable building solutions that enhance the built environment. The primary goal of the Engineering for One Planet (EOP) Framework is to provide engineers with the necessary skills and knowledge to safeguard the planet and its ecosystems, ensuring their sustainability for the benefit of all living beings. This project focused on introducing students in the Civil Engineering Technology five-year Bachelor of Science Program at Rochester Institute of Technology to sustainability concepts using the EOP framework. Curricular changes were implemented for two courses in the Civil Engineering Technology Program, a first-year introduction to civil engineering course reaching 72 students and a fourth-year structural steel design course reaching 30 students. The course materials introduced students to sustainability concepts for building and infrastructure projects. The students engaged in educational activities that offered them opportunities to enhance their comprehension of the course content and internalize sustainability principles at a deeper level. At the end of the semester, more than 80% of the students reported an improvement in their understanding of sustainability-related concepts and over 90% of the students said they had a better understanding of how civil engineers can contribute to a sustainable world according to the survey results. Using the two courses as pilot studies, this project aims to integrate sustainability concepts into other technical courses to equip students with a strong foundation and the necessary skills to become agents of change in promoting sustainability within the civil engineering and construction industry.

Keywords: sustainability, civil engineering, curriculum

Introduction

Civil engineers serve as master builders, environmental stewards, innovators and integrators, managers of risk and uncertainty, and leaders in shaping public policy (ASCE, 2019). Civil engineering has a significant impact on the environment, and it is crucial to ensure that infrastructure development is sustainable and does not harm the natural environment. Therefore, civil engineering education must emphasize sustainability and educate future civil engineers on the sustainable design, construction, and operation of infrastructure systems. Although buildings are perceived to be the most advanced field in relation to sustainability (Mesa et al., 2017), students graduating with civil engineering degrees who work on building and infrastructure projects do not have adequate knowledge of sustainability concepts. With the rapid growth of sustainability initiatives and emerging technologies globally, civil engineering education needs to be adapted to accommodate technological innovations and promote a culture of sustainability.

The primary goal of the Engineering for One Planet (EOP) Framework is to provide engineers with the necessary skills and knowledge to safeguard the planet and its ecosystems, ensuring their sustainability for the benefit of all living beings (EOP, 2020). Rochester Institute of Technology is committed to advancing sustainability on campus and in the curriculum. Efforts are also in place to develop innovative and interdisciplinary academic programs to support its commitment to sustainability. The Civil Engineering Technology program at Rochester Institute of Technology is well poised to incorporate curricular changes that incorporate sustainability and innovation. This project focused on introducing students in the Civil Engineering Technology Program to sustainability concepts using the EOP framework. Curricular adaptations were implemented for two courses: Introduction to Civil Engineering and Structural Steel Design, both in the Civil Engineering Technology Program reaching 102 students. The two pilot courses served as examples to incorporate sustainability concepts into other technical courses within the program to ensure the students are well-grounded and prepared to be sustainability change agents in their future careers in the civil engineering and construction industry.

Introduction to Civil Engineering is a required first-year course for students in the Civil Engineering Technology Program where they are introduced to basic concepts in civil engineering. The objective of this course is for the students to develop an understanding of plans and drawings in civil engineering projects such as site development, structures, hydraulic structures, water and wastewater transport and treatment facilities, and transportation facilities. Students will also understand how related disciplines—architecture, mechanical and electrical engineering, and landscape architecture—are incorporated into construction drawings. Students will develop an understanding of the technical and legal purpose of plans and how to assemble them. Structural Steel Design is a required course for fourth-year students in the Civil Engineering Technology program. It involves the design of structural members and frames and their connections in steel structures. Topics include principles of structural design and the code of ethics in engineering practices, structural loads and systems, steel grade and shapes, steel framing and deck design, tension members, compression members, non-composite beams, beam-columns, column base plates, bolted connections and welded connections.

The EOP framework provides guiding principles for engineering educators to incorporate sustainability concepts into their courses. The aim of this study is to integrate the EOP framework into two courses in the civil engineering technology program at the higher education institution and explore the students' understanding of sustainability-related content and measure their engagement with the material and confidence in carrying out the EOP learning outcomes that aligned with respective courses. The goal is to increase students' interest in sustainability principles and concepts and encourage other faculty to adopt the EOP framework for their courses.

Background

The integration of sustainability principles, practices, and values is critical for engineering education. Civil engineers, in particular, should demonstrate an understanding of sustainability to prepare them to address global challenges, promote ethical practices, meet industry trends, and exhibit problem-solving skills. Interviews with senior-level civil engineering students at a higher education institution revealed that they did not learn how sustainability was related to their coursework (Salzman et al., 2018). Accreditation agencies such as Accreditation Board for Engineering and Technology (ABET) incorporate sustainability-related student outcomes into their criteria requiring that students have "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" also students should have "an 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" (ABET, 2021). Understanding sustainability is an essential skill for civil engineering students and aspiring industry professionals to position them as responsible professionals who can plan, design, build, operate, and maintain buildings and infrastructure to meet societal needs. Bielefeldt (2011) observed that environmental engineering and civil engineering students intuitively considered sustainability concepts in their assignments when not required to after taking a newly introduced first-year sustainability module. Students were able to realize and demonstrate the importance of sustainability in their work.

Pedagogical approaches for teaching sustainability in civil engineering

Sustainability concepts can be incorporated into civil engineering education through curriculum changes to the course content, involving students in research on sustainability-related topics, collaborating with industry partners to allow students gain exposure and work on real-world projects, and pedagogical approaches such as project-based learning, problem-based learning, and case studies. Gutierrez-Bucheli et al. (2022) suggested teaching sustainability using project-based approaches that reflect the culture and context of the students to enable them to frame their understanding of sustainability. Vemury et al. (2018) also found that problem and project-based approaches using real-world problems were beneficial in teaching sustainability to civil engineering students. Furthermore, Mesa et al. (2017) encouraged the use of case studies and exploring industry-academia collaborations to provide students with access to real-world engineering problems and increase their interest in the subject. Sustainability in engineering education should not be restricted to environmental sustainability as studies have recognized the importance of teaching students about the social and economic aspects as well to broaden their understanding and assess a variety of viewpoints. Sustainability concepts are sometimes taught in stand-alone courses or integrated into existing courses, in engineering education, sustainability should be integrated into all courses with students having the option to delve deeper into the concepts in stand-alone courses. Students also need to be aware of connections between different aspects of their courses and potential real-world applications. Burian (2011) briefly introduced sustainability concepts in lower-level courses and provided modules and projects to teach students in higher-level courses. A variety of pedagogical approaches are suitable for achieving sustainability-related learning outcomes at various levels of the Blooms taxonomy (Bielefeldt, 2013).

Engineering for One Planet (EOP) framework in the curriculum

Engineers play a critical role in achieving global sustainability goals. The EOP framework is an implementation tool designed to transform engineering education (EOP, 2022). It was developed by The Lemelson Foundation and VentureWell in 2019 and was revised in 2022 after incorporating comments from different stakeholders. The framework addresses different learning outcomes in eight major categories namely design, material choice, environmental impact measurement, social responsibility, responsible business and economy, environmental literacy, communication and teamwork, and critical thinking as depicted in Figure 1. The learning outcomes under each category are also separated into core and advanced-level outcomes. The EOP learning outcomes align with learning outcomes for engineering courses and they also address the seven ABET student outcomes and the 17 United Nations Sustainable Development Goals (UN SDGs) (UN, 2015). Systems thinking is at the center of the framework to foster students' ability to make connections as they gain knowledge, develop technical expertise, and build communication and leadership skills essential for success as engineers and construction managers.

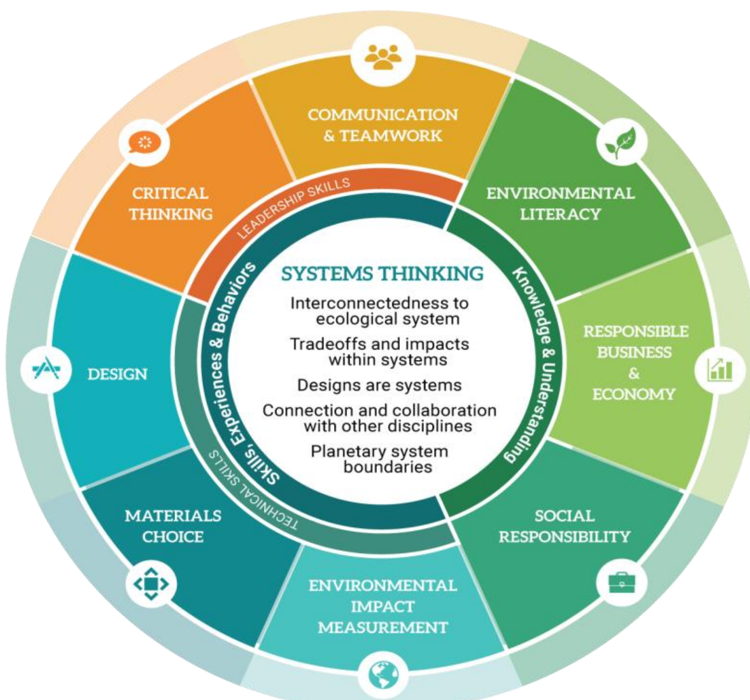

Figure 1: Engineering for One Planet (EOP) Framework (Source: EOP, 2020)

The EOP framework has been adopted in a few higher education institutions and was used in project-based learning courses (Larson et al., 2021; Woolard et al., 2022) and in other courses at the graduate and undergraduate levels (Welker et al., 2022). Larson et al. (2021), focused on the impact of a second-year course within an engineering program on students' understanding of environmentally responsible engineering using the EOP framework. Woolard et al. (2022), used an outcomes-based approach to modify several courses within their environmental engineering curriculum. Welker et al. (2022), assessed EOP outcomes in three civil engineering courses through assignments, exam questions, and group projects. This project focused on the implementation of the EOP framework in existing courses within the Civil Engineering Technology department, focusing on EOP learning objectives taught in selected courses.

Methodology

Study description

The Civil Engineering Technology program at Rochester Institute of Technology is a five-year Bachelor of Science (BS) program with one-year required cooperative education internship, and is accredited by Engineering Technology Accreditation Commission of ABET. The BS program curriculum design emphasizes the practical theory, knowledge, and skills necessary to analyze and solve complex challenges posed by the increasing building and infrastructure needs. The BS curriculum is currently in the process of being enhanced to incorporate the latest technologies and sustainable concepts, integrating experiential and active learning techniques (Abraham, 2020; Abraham et al., 2022; Bao, 2020; 2022). As part of this study, sustainability concepts were integrated into two existing courses- two sections of introduction to civil engineering and one section of structural steel design taught by three different instructors within the Civil Engineering Technology program during the Fall of 2022. Table 1 provides a summary of the courses included in this study.

Table 1: Information of courses with EOP curricular changes

Courses with EOP Curricular Changes	Level	Number of Students Enrolled	Number of Survey Responses	Sustainability-related Course Activities
CVET 180-1: Introduction to Civil Engineering	First year	38	17	Guest lectures, mini field trips, exam questions, discussions, group exercises, and assignments.
CVET 180-2: Introduction to Civil Engineering	First year	34	29	
CVET 431: Structural Steel Design	Fourth year	30	30	

Students participated in learning activities that provided opportunities to imbibe core concepts and deepen their understanding of sustainability. The impact of engineering decisions was emphasized in these courses to promote "sustainability" more broadly in solving complex engineering problems. The course learning outcomes for introduction to civil engineering and structural steel design were mapped to EOP learning outcomes as outlined in Tables 2 and 3.

Surveys were administered to gather feedback from students enrolled in both courses to evaluate their understanding and confidence in applying key EOP concepts mapped to the course learning objectives. The survey questions were developed and the research protocol was submitted to the Institutional Review Board (IRB) at the authors' institution for review and approval before being administered to the students. Hard copy surveys were preferred to email/web-based surveys to increase the response rate since research indicates that email surveys have a lower response rate than paper surveys (Shih and Fan, 2009; Ebert et al., 2018).

Data collection

In the fall semester of 2022, students in the introduction to civil engineering course completed an assignment to sketch a civil engineering solution addressing one of the UN SDGs, they also discussed the difference between steel and reinforced concrete considering their weight, recyclability, strength, adaptability, and environmental impact. Their map reading assignments included questions on material selection, environmental responsibility, and life cycle impacts. They also completed a sustainable building walkthrough where they identified sustainable features and gained exposure to sustainable building rating systems. Guest lectures were also organized for the students to relate their course materials with real-world applications and also increase awareness of their career options.

Three new homework assignments were designed and implemented in the structural steel design course. In the new course materials, students were asked to compare and justify the design options with different recyclable contents, strengths, weights, construction speed, ease of maintenance and deconstruction, and the impact on the environment.

At the end of the semester, the hard-copy survey questionnaires were distributed in class for both courses to gather students' feedback. They were asked an open-ended question to define sustainability in their own words, and indicate how their understanding of sustainability changed since the beginning of the semester on a five-point scale ranging from "significantly decreased" to "significantly improved." They also indicated their level of agreement or disagreement relating to their understanding of how engineers can contribute to a sustainable world as a result of the course. Finally, they were asked about their levels of engagement with different sustainability-related competencies and their confidence in carrying out these competencies. The competencies were mapped to the course learning outcomes. The surveys were distributed in class and the students were invited to complete them voluntarily, they were asked not to include their names to ensure anonymity. The completed surveys were collected in class. All 30 students in the structural steel design course completed and submitted the survey while 46 out of 72 did in both sections of the introduction to civil engineering course (Table 4). The responses were transferred to a spreadsheet format for analysis. Responses to the open-ended questions were analyzed using NVivo to identify key themes and other responses were analyzed in Microsoft Excel to provide descriptive statistics.

Table 2: Mapping of EOP learning outcomes to "Introduction to Civil Engineering" learning outcomes

Course Learning Outcomes	EOP Learning Outcomes
Understand the fundamentals of civil engineering graphics	ST- Demonstrates awareness that a design is a system, that users interact with designs and that designs and users are embedded in higher-level systems that include environmental ecosystems and the life they sustain.
Create fundamental civil engineering graphics elements	D- Is able to set design goals and use technical analyses to choose strategies that minimize environmental impact. CT- Communicates through audience-specific written, graphic/visual, oral and interpersonal communication skills.
Interpret construction drawings for different civil engineering disciplines	CT- Understands that every person has a role in being environmentally responsible and has the right to be informed about the environmental/social/economic impacts of the products they purchase, consume and discard.
Distinguish different civil engineering disciplines and understand the basics of sustainable design	ST- Demonstrates whole system awareness with the ability to identify and understand interconnectedness (intersecting, related and/or connected systems; synergies and rebound effects) and how all human-made designs rely upon and are embedded within ecological systems. ST- Demonstrates awareness that all work is connected to other disciplines and understand when and how to collaborate and consult with others. SR- Is familiar with the United Nations Sustainable Development Goals (SDGs).
Describe the importance of construction drawings	ST- Is able to consider temporal outcomes of present decisions (i.e., life-cycle effects through time for future generations.

Key: CT- Communication and Teamwork, D- Design, ST- Systems Thinking, and SR- Social Responsibility

Table 3: Mapping of EOP learning outcomes to "Structural Steel Design" learning outcomes

Course Learning Outcomes	EOP Learning Outcomes
Calculate dead, live, snow, wind and seismic loads acting on building structures and components using ASCE 7 Code	D- Is able to set design goals and use technical analyses to choose strategies that minimize environmental impact.
Identify vertical and lateral load paths in building structures.	ST- Demonstrates whole system awareness with the ability to identify and understand interconnectedness (intersecting, related and/or connected systems; synergies and rebound effects) and how all human-made designs rely upon and are embedded within ecological systems.
Select appropriate structural systems for resisting lateral loads in building structures.	ST- Is able to consider and understand tradeoffs and identifies impacts between different parts of the system (i.e., environmental, economic and social considerations).
Design basic structural elements in steel such as beams, columns, connections, lateral braces and floor systems using AISC Steel Construction Manual and the International Building Code.	D- Is able to set design goals and use technical analyses to choose strategies that minimize environmental impact. D- Is able to design for the environment based on discipline-specific technical skills (e.g., light-weighting).
Present design information in the form of design calculations, structural plans, sections and details.	ST- Demonstrates awareness that all work is connected to other disciplines and understands when and how to collaborate and consult with others. CT- Communicates through audience-specific written, graphic/visual, oral and interpersonal communication skills.
Operate on a team to prepare the design of a steel structure, and present the design both orally and via a written design report, citing all reference materials.	ST- Demonstrates awareness that all work is connected to other disciplines and understands when and how to collaborate and consult with others. CT- Communicates through audience-specific written, graphic/visual, oral and interpersonal communication skills. CT- Works within and functions well across disciplines.
Identify the ethical and professional responsibilities in structural design practices.	SR- Understands the role of social responsibility in the engineering profession.

Key: CT- Communication and Teamwork, D- Design, ST- Systems Thinking, and SR- Social Responsibility

Results and discussion

Definition of sustainability- the first-year students were introduced to basic concepts in sustainability at the beginning of the semester and both the first- and fourth-year students were exposed to the concepts during the course of the semester. Responses to the open-ended question on the students' understanding of sustainability are summarized in the word clouds below (Figures 2a and b). At the end of the semester when the surveys were administered, students in both courses were able to articulate their definitions of sustainability using relevant terms and keywords. The most frequently used words for students in CVET 180 were "environment," "resources," and "using." According to the 30 responses from students in CVET 431, The most frequently mentioned words were related to efficient "materials," "use," and "designs." Students in the introductory course seemed to relate sustainability with the environment and the use of resources while students in the advanced level course (structural steel design) mentioned material use and design associating sustainability to the topics discussed in their course. Students also demonstrated this knowledge through their assignments which supports the findings of Bielefeldt (2011) indicating that emphasizing sustainability concepts early can impact their understanding of its importance in civil engineering.

(a) (b)

Figure 2: Word cloud of responses from (a) Introduction to Civil Engineering (CVET 180) students, (b) Word cloud of responses from Structural Steel Design (CVET 431) students

Understanding of sustainability-related concepts: Students were asked to indicate how their understanding of sustainability concepts changed since the beginning of the semester. For CVET 180-1, 82.4% of the students selected "improved," while 17.6% of the students selected "unchanged" (Figure 3).

For CVET 180-2, 27.6% of the students chose "significantly improved", 69% of the students selected "improved", 3.4% of the students felt "unchanged." For CVET 431, 20% of the students chose "significantly improved", 63.3% of the students selected "improved", 16.7% of the students felt "unchanged." For the three cases, no students selected "decreased" or "significantly decreased". Understanding of sustainability-related content improved for the majority of the students indicating that the learning activities helped them engage in the topic. Others that mentioned that it was unchanged may have had prior exposure to sustainability-related concepts introduced in the class.

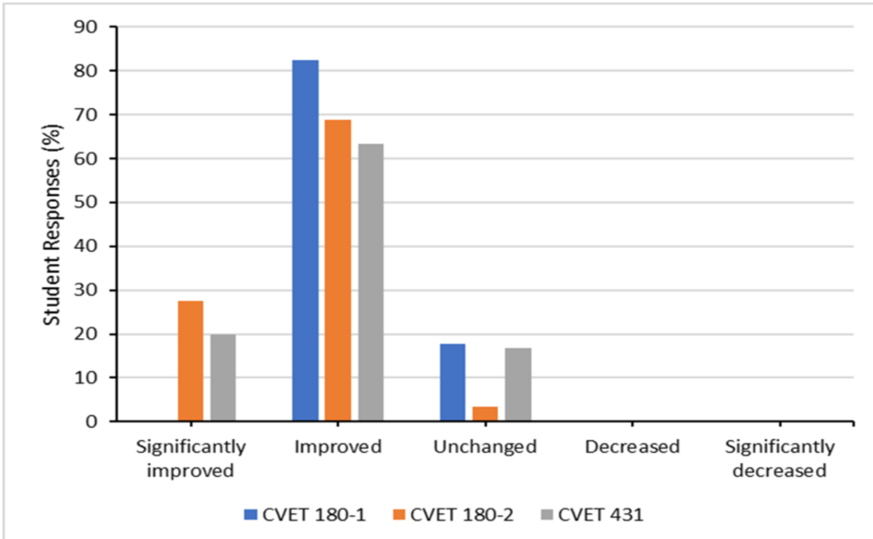

Figure 3: Responses on students' understanding of sustainability-related concepts

Understanding of how civil engineers can contribute to a sustainable world: students were asked to indicate their level of agreement or disagreement relating to their understanding of how engineers can contribute to a sustainable world as a result of the course.

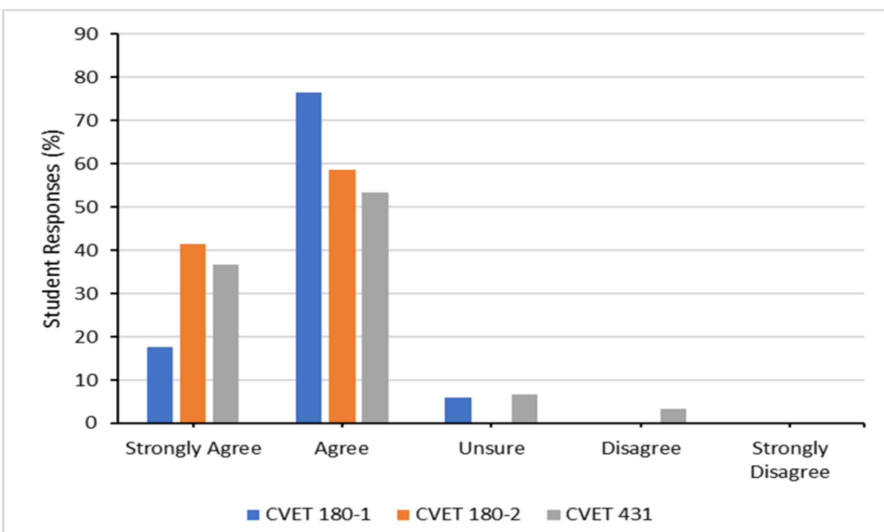

Figure 4: Responses on the understanding of how civil engineers can contribute to a sustainable world

For CVET 180-1, 17.6% of the students selected "strongly agree", 76.5% of the students chose "agree", 5.9% of the students were "unsure." For CVET 180-2, 41.4% of the students selected "strongly agree" and 58.6% of the students chose "agree. For CVET 431, 36.7% of the students selected “strongly agree”, 53.3% of the students chose “agree”, 6.7% of the students “unsure”, 3.3% of the students “disagree.” Students generally agreed with the statement that they had a better understanding of how civil engineers can contribute to a sustainable world with a very small percentage indicating that they were unsure or disagreed. The students that were unsure or disagreed may have had this understanding prior to taking the course and they did not feel like the course made any change in that regard. The guest lectures were geared toward directly addressing this topic, also course materials referred to civil engineering contributions through case studies, assignments, and examples.

Engagement and confidence with top three EOP outcomes: Students indicated their level of engagement and confidence in carrying out the EOP learning outcomes that were mapped to their course learning outcomes (Table 5). Over 82% of students in both sections of the introduction to civil engineering course reported that they engaged moderately or largely with the content, while 92% indicated high, very high, or moderate confidence in carrying out the learning outcomes. Over 93% of students in structural steel design reported that they engaged moderately or largely with the content, while 100% indicated high, very high, or moderate confidence in carrying out the learning outcomes.

Table 5: Engagement and confidence with top three EOP outcomes

	CVET-180-01	**CVET-180-02**	**CVET-431**
1	Communicates through audience-specific written, graphic/visual, oral, and interpersonal communication skills. *82.4% engagement, 100% confidence.*	Communicates through audience-specific written, graphic/visual, oral, and interpersonal communication skills. *82.1% engagement, 92.9% confidence.*	Design for the environment based on light-weighting and material efficiency. *100% engagement, 100% confidence.*
2	Understand that every person has a role in being environmentally responsible. *94.1% engagement, 100% confidence.*	Understand that every person has a role in being environmentally responsible. *89.3% engagement, 100% confidence.*	Understand the connection with other disciplines and initiate effective collaboration and consultation. *96.7% engagement, 100% confidence.*
3	Aware of civil engineering disciplines and career options in civil engineering. *88.2% engagement, 93.3% confidence.*	Aware of civil engineering disciplines and career options in civil engineering. *86.2% engagement, 96.6% confidence.*	Understand the role of social responsibility in the engineering profession. *93.3% engagement, 100% confidence.*

Note: Percent engagement indicates engaged moderately or largely with the content, and percent confidence indicates high, very high, or moderate confidence in using the competency.

These findings indicate that incorporating the EOP framework to teach sustainability concepts in different courses was a beneficial tool when aligned with the course learning outcomes and a variety of pedagogical approaches. First-year students reported less engagement with some learning outcomes while the fourth-year students were more engaged and more confident in the top three learning outcomes related to their course. This could be because some of the students did not directly associate the class activities with the learning outcomes or they did not have adequate opportunities to engage with the course materials due to other factors such as absenteeism and lack of motivation (Bather, 2013). Senior-level students were more able to apply systems thinking to solve complex problems related to their course content. They had gained confidence through their course of study and were more ready and able to demonstrate an understanding of those competencies.

Conclusions

Engineering students should learn about sustainability during their program and be adequately prepared to address societal challenges. The EOP framework is a tool that enables instructors to embed sustainability in their courses while challenging students to address complex issues, make connections, and apply systems thinking to address those challenges. For the two pilot courses selected for EOP implementation, introduction to civil engineering and structural steel design, the course learning objectives were mapped to the EOP learning objectives and as reported in the surveys, the students' ratings of engagement and confidence in applying the competencies align with the level of the students and types of activities implemented in each course. The success of the two pilot courses have laid a solid foundation to further the EOP framework implementation into the Civil Engineering Technology curriculum.

Overall, more than 80% of the students indicated an improvement in their understanding of sustainability-related concepts and over 90% of the students said they had a better understanding of how civil engineers can contribute to a sustainable world. Although first-year students reported less engagement with some learning outcomes than fourth-year students, the percentage of students that reported moderate or large engagement with the course content was high. The students regardless of their academic level were largely confident in carrying out competencies related to the course learning outcomes.

One of the limitations of this study is the focus on a selection of courses, one at the introductory level and the other at the senior level, as part of the pilot study. Also, a pre- and post-test could have provided a more comprehensive understanding of the initial understanding of sustainability-related concepts to assess the improvement in learning. Future plans include incorporating the EOP framework into other core courses and technical electives taught in the civil engineering technology program incrementally and promoting the adoption by other faculty. This will ensure that students can build upon prior knowledge as they go through the program. This study will be beneficial to faculty considering incorporating sustainability concepts into their courses using the EOP framework.

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