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Integrating Engineering for One Planet Principles in Engineering Design Curriculum

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Abstract

The Sustainable Systems Engineering Program at the University of Calgary has been significantly influenced and inspired by the Engineering for One Planet (EOP) Framework since its inception. While we have made several efforts to integrate EOP principles throughout the entire curriculum during the first two years of the program, this paper specifically focuses on their integration within an Engineering Design course developed for second-year students. In this paper, we will describe the curriculum design, highlight insights from the teaching team, and provide a thorough analysis of the learning outcomes associated with this integration.

Parallel to the EOP framework, at the core of our design courses is a foundation in systems thinking, which empowers students to tackle challenges from a holistic perspective. They were not only encouraged to develop solutions to challenges, but also to explore and map the 'interconnectedness' among various systems and the 'dynamic impacts' among parts of the systems as well as making links to the 17 United Nations Sustainable Development Goals (SDGs). Collaborative projects were an integral part of our design course, where students work in teams to tackle complex, open-ended, wicked problems framed around key sustainability themes. These projects were co-developed with the Office of Sustainability at the University of Calgary and require not only technical skills but also creativity, critical thinking, and effective communication. By engaging with real-world challenges, students consider diverse perspectives and develop inclusive solutions that address the needs of various stakeholders, all while learning to apply different sustainability tools and frameworks in their designs, specifically to 'maximize the positive and minimize the negative environmental and social impacts'. We also leveraged sustainability design cards to support students in applying 'specific technical skills' such as design for repairability, reuse, and disassembly. Reflections from our first iteration showed that integrating EOP principles into our Engineering Design curriculum has created a positive learning environment.

1. Introduction

Engineers play a vital role in shaping the built environments that support and enhance life in the twenty-first century [1, 2, 3]. Addressing the global challenges of sustainability requires rethinking engineering education to align more closely with principles that emphasize the interconnectedness of environmental, social, and economic systems [4]. The green skills report also highlights the urgent need to address the "Green Skills Gap" by hiring qualified personnel for sustainability-focused roles[1]. At the University of Calgary, a new Sustainable Systems Engineering program was launched in 2023, with the aim of equipping graduates with the necessary skills to tackle the complex global challenges, the mounting climate crisis, and societal injustices. The design spine courses in this new program specifically aim to foster critical thinking, systems thinking and design, and sustainability mindsets.

To support the development of the second-year Introduction to Sustainable Systems Design course (SUSE 300), we leveraged the Engineering for One Planet (EOP) Framework [5]. This framework centers systems thinking and provides guidance for developing knowledge and

[1] https://economicgraph.linkedin.com/research/global-green-skills-report

understanding alongside the necessary skills, experiences, and behaviors. Figure 1 below shows an early version of curriculum mapping completed in Tableau, showing how the curriculum was aligned with the competencies outlined in EOP Framework. Figure 1 specifically highlights SUSE 300 (originally called SUSE 301) and the competencies planned for this course.

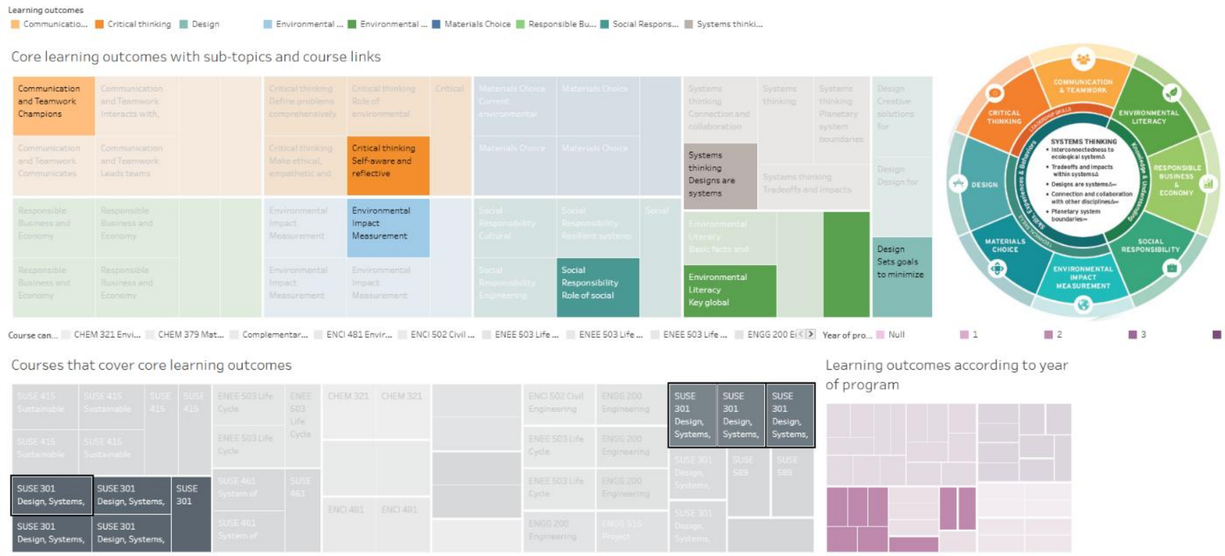

Figure 1. Early Curriculum Mapping of SUSE to EOP Framework

Overall, this paper provides a case study example of implementation of the EOP Framework. After a literature review covering frameworks for sustainability and pedagogies for sustainability education, we detail our course approach, reflections from the first iteration, and future directions. This paper contributes to the growing literature that calls for different approaches to training engineering students for tackling the climate crisis [6] as well as for the growing network of engineering educators at the ASEE conferences who are discussing their approaches to integrating EOP principles into curricula (e.g. over 40 papers have been published in ASEE conferences on EOP since 2021).

2. Literature Review

2.1 Frameworks for sustainability engineering education

One tool to support shifting engineering education to build skills for a sustainable future is Education for One Planet (EOP), a framework that seeks to integrate sustainability into curricula by equipping students with the knowledge, skills, and values necessary to address complex, real-world challenges [7]. By embedding EOP principles into design education, engineering students are prepared not only to understand these challenges but also to create solutions that are innovative and sustainable. EOP draws heavily on the foundations of Education for Sustainable Development (ESD), which emphasizes interdisciplinary learning, critical thinking, and problem-solving strategies aimed at achieving sustainable outcomes. Furthermore, integrating EOP principles aligns with Canadian accreditation requirements [8] and institutional goals [9] to produce graduates who are socially responsible and capable of addressing sustainability challenges through their professional practice [10]. To achieve these goals, engineering curricula must adopt strategies that bridge theoretical knowledge with practical applications, fostering a systems-oriented mindset among students. The EOP Framework centers (1) systems thinking at its core, with the essential (2) knowledge and understanding and (3) skills, experiences, and behaviors (technical and leadership) surrounding (see Figure 2).

Figure 2. Engineering for One Planet Framework (reproduced from [5])

The adoption of the United Nations Sustainable Development Goals (SDGs) is another framework that has further strengthened the integration of sustainability into the engineering education curricula. These 17 global objectives provide a roadmap for addressing critical issues such as poverty, clean energy, and climate action [11]. In the context of engineering design education, the SDGs serve as a foundation for project-based learning, allowing students to engage with real-world problems in a meaningful way. For instance, design projects often focus on renewable energy systems or sustainable urban infrastructure, enabling students to explore the practical implications of sustainability within the context of global challenges. Such initiatives are supported by studies that emphasize the importance of connecting SDG-focused projects with interdisciplinary collaboration to prepare students for the complexities of professional practice [10].

2.2 Pedagogies for sustainability engineering education

Existing literature [7, 12, 13] highlights that essential competencies to cultivate in engineering undergraduates for advancing Education for Sustainable Development (ESD) include integrated problem-solving, self-awareness, critical thinking, collaboration, normative competence, and systems thinking. These competencies are considered crucial for addressing complex sustainability challenges and are best fostered through active learning approaches [14, 15, 16]. Active learning strategies such as problem-based learning (PBL) have been specifically identified as effective in developing these skills [14].

Incorporating systems thinking pedagogies into engineering education is critical for addressing the multifaceted nature of sustainability challenges [17, 18]. Systems thinking provides a framework for understanding the interconnections within complex systems, enabling students to identify synergies, trade-offs, and leverage points. This approach not only enhances their analytical skills but also equips them to engage in stakeholder dialogue, life-cycle assessment, and decision-making under uncertainty [19, 20]. The application of systems thinking principles in undergraduate programs often takes the form of simulations, case studies, and interdisciplinary projects, allowing students to develop a more holistic understanding of engineering challenges [17]. By doing so, engineering education moves beyond traditional reductionist approaches, fostering the capacity to address the interconnected dimensions of sustainability.

Project-based learning (PBL) serves as a complementary strategy in embedding EOP principles into engineering curricula. PBL provides students with opportunities to engage in collaborative projects that simulate professional practice, fostering critical thinking, creativity, and teamwork [21]. These projects are designed to address complex problems, including wicked problems—issues characterized by conflicting stakeholder values, incomplete information, and evolving constraints [22]. For instance, engineering students may work on projects such as designing sustainable transportation systems or renewable energy solutions, integrating technical, social, and economic considerations. This hands-on approach not only enhances student engagement but also prepares them to tackle real-world challenges with innovative solutions.

While the integration of EOP principles into engineering education represents significant progress, challenges remain. Traditional educational practices often encourage the separation of objects from their context and the fragmentation of disciplines, leaving students ill-prepared to address the complexity of sustainability challenges [23, 24]. This compartmentalization strains the metaphorical threads that connect the fabric of understanding, making it difficult to reweave them into a cohesive whole. Addressing these gaps requires a holistic approach that emphasizes systems thinking and interdisciplinary collaboration, ensuring that students are equipped to navigate the complexities of sustainability in their professional practice [25, 26].

In this context, the integration of EOP principles into design classes represents a critical step forward. By aligning engineering education with the principles of sustainability, we can better prepare students to address the challenges of the twenty-first century, fostering a generation of engineers who are not only technically proficient but also socially and environmentally conscious. This paper explores a case study of how EOP principles can be effectively embedded into design education, building on the strategies and frameworks outlined in the literature to create a transformative learning experience for engineering students.

3. Methodology: Case Study of Pedagogical Innovation

The methodology of this paper describes the implementation of a pedagogical innovation as a case study exemplar. Innovation means to add something new, change a project a process, and/or influence mindsets– not just in plan, but in execution [27, 28]. Specifically, pedagogical innovation is “an intentional action that aims to introduce something original into a given context, and it is pedagogical as it seeks to substantially improve student learning in a situation of interaction and interactivity” [29 and as cited in [30], p. 196].

Our topic of interest is to understand the pedagogical innovation and implementation of EOP into the SUSE 300 course curriculum, thus we aim to learn about this particular single-case and aim to "capture the complexity of the object of study" [31] as cited in [32]. This research is still preliminary research and a work-in-progress, so we present only high-level context and reflections of the case. Ethics approval is underway, but as it is not yet approved, at this time we are unable to provide student feedback.

4. Our Case Study and the Approach in Integrating EOP

4.1 The Case Study: SUSE 300 Introduction to Sustainable Systems

In this section, we present our case study (SUSE300) reflecting on our experience from its first iteration in Winter 2024. As we implement the second iteration in Winter 2025, we aim to leverage this learning experience to improve the integration of the EOP Framework into the course.

The course was primarily structured around design projects. Student teams of 4-5 members, worked on an open-ended project based on their interest within five thematic areas provided: renewable energy integration, sustainable construction and sustainable product design/redesign, sustainable resource consumption and circularity, sustainable water management and green landscaping, and sustainable transportation. We collaborated with experts from the Campus as a Learning Lab initiative of our university's Office of Sustainability. This partnership helped co-develop some of the students' projects and ensured that their work was relevant to the campus community, serving as a baseline for real-world applications. The project titles were *The Dynamic Ducks*, focused on stormwater management through natural processes; *Solar Shaders*, aimed to integrate solar panel arrays into parking lots for sustainable energy and electric vehicle infrastructure; *Green Lines, Green Actions*, reimagined urban transportation from a sustainability perspective; *Re-Decor*, sought to upcycle used furniture by incorporating functional, easy-to-maintain, and eco-friendly hydroponic systems; and *Garden Gang*, explored and designed a rooftop greenhouse.

To support students in the design process and establish a strong foundation in the fundamentals, weekly lectures mixed content, guest lectures, hands-on activities, and open worktime.
The semester was organized based on agile project management and split into three sprints, each serving as a milestone in the iterative design process. These sprints were planned to align with key project phases: prototype development and showcases, midterm project submissions, and final presentations with accompanying design reports. Together, these activities accounted for 75% of the final grade. Each showcase and in-class presentations provided students with opportunities to present their work to peers, instructors, and experts (Office of Sustainability and invited guests) fostering a collaborative environment with constructive feedback. and professional insights and guidance at every stage. The remaining 25% of the final grade was allocated to students' reflections, retrospectives, and final design portfolio, which we structured to encourage continuous self-assessment and growth throughout the learning process. These activities were designed to prompt students to reflect on their experiences, identify their and their team's strengths and areas for improvement, and consider how their learning evolved over time, evaluate their progress in real-time, and provide them the opportunity to make meaningful adjustments to their strategies and approaches before moving forward.

4.2 Our approach in integrating EOP Framework

The following section of this paper outlines the activities we integrated into our course to embed the core principles of the EOP Framework [5], focusing on (1) systems thinking, (2) knowledge and understanding, and (3) the development of skills, experiences, and behaviors (both technical and leadership).

4.2.1 Systems thinking

The first learning outcome (of nine total) of SUSE 300 course focused on *'applying fundamental engineering design and techniques to address complex challenges'.* Tackling these challenges-often referred to as "wicked problems" due to their interconnected nature-requires a solid understanding of systems thinking. Recognizing this, we introduced students to the concept of systems thinking early in the course through a foundational lecture titled *"Systems Thinking in Design."* This lecture provided students with a comprehensive introduction to systems thinking, beginning with the fundamental question: What is a system? We explored different types of systems, such as simple, complicated, and complex, and examined how systems thinking provides a structured approach to understanding and solving complex systems. Students learned how systems thinking complements traditional design thinking, enabling them to analyze problems holistically and identify interdependencies between components. This lecture also covered essential tools like system mapping, the iceberg model, and causal loop diagrams (CLDs) to help students visualize and analyze systems effectively. One of the key deliverables of the course was the midterm report, where students were tasked with applying these tools by framing their design problem and mapping the interconnected elements of the system or creation of a CLD to support their analysis. This emphasis on systems thinking not only prepared students to tackle the immediate challenges of the course but also equipped them with a critical mindset and practical tools for addressing the complex, systemic problems they will encounter in their future careers.

4.2.2 Knowledge and understanding and technical skills, experience, and behaviors

To provide students with a comprehensive foundation in sustainable systems design, we structured a series of lectures addressing core concepts, including sustainable design and design thinking, sustainability tools, design justice. These lectures were developed to bridge theoretical understanding and practical application, and approach design challenges with a sustainability and system thinking mindset.

The sustainable design and design thinking lecture introduced students to the iterative stages of the design process: empathize, define, ideate, prototype, and test. We emphasized the importance of human- and community-centered design, encouraging students to prioritize the needs, values, and experiences of diverse stakeholders. To deepen their understanding of global sustainability challenges, we discussed the interconnected nature of the United Nations Sustainable Development Goals (SDGs), highlighting how systems thinking is critical to addressing overlapping social, environmental, and economic issues. Students were also introduced to Canada's 2050 net-zero emissions targets and key climate mitigation strategies, providing a local and actionable context for applying sustainability principles [33]. We further examined the evolving role of engineers in sustainable design, emphasizing their responsibility not just as problem-solvers but also as facilitators of innovation and agents of positive change. This discussion encouraged students to critically evaluate how their work could drive sustainable solutions to complex and interconnected challenges.

The sustainability tools lecture introduced versatile tools such as Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), risk assessments, and input-output analysis. To ensure students could effectively integrate these tools into their projects, we incorporated hands-on activities where they practiced selecting and applying the most appropriate tools to their term projects. Dedicated in-class work time allowed them to collaborate with peers, ask questions, and refine their approaches under the guidance of instructors. A significant emphasis was placed on the use of sustainability indicators/matrices to evaluate project outcomes. Students were encouraged to move beyond traditional metrics, such as GDP, which primarily focus on economic growth, and instead adopt multi-dimensional indicators that capture environmental, social, and economic impacts, equipping them to consider diverse outcomes and trade-offs in their decision-making.

We also introduced the concept of the impact matrix [34], a tool designed to help students systematically analyze each stage of their design process. Using this matrix, students identified the inputs (such as materials and energy) and outputs (including emissions, waste, and byproducts) at every phase. This approach enabled them to assess potential sustainability impacts and identify opportunities for improvement, from material selection to energy efficiency and waste reduction.

We introduced Sustainability Design Cards [35] as an interactive and engaging tool to help students systematically explore diverse aspects of sustainability and effectively integrate them into their projects. During the lecture, we provided students with a detailed example of how these cards could be utilized in the context of their projects. Each card presented a specific sustainability concept or challenge-such as environmentally friendly materials, embedded storytelling, minimizing waste, design for disassembly, ethical supply chain, or local production-along with guiding questions, challenges, or actionable examples (see Figure 3 for example). This allowed students to consider sustainability not as an abstract concept but as a practical and integral part of their design process and project (that pushed them beyond material selection as a primary sustainable design consideration).

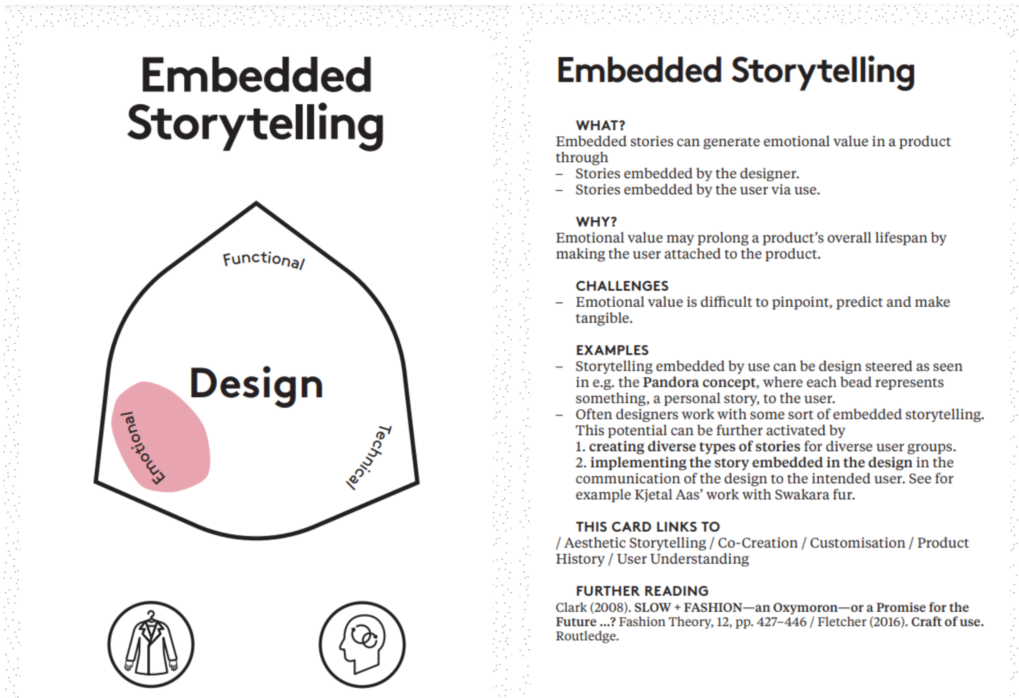

Figure 3. Example of Sustainability Cards, (reproduced from [35]).

In engineering, sustainability is often emphasized from environmental and economic perspectives, often overlooking social sustainability. To address this gap, we included a lecture on "design for justice" [36] to help students understand how engineering designs can distribute benefits and burdens across different groups of people. This encouraged them to consider aspects of social justice and inclusive design as a critical project consideration. Aligned with the "15 Sustainable Design Principles" [37], students were also encouraged to apply the "10 Principles of Design Justice" [38] in their design projects. Additionally, we invited a guest speaker from the Gender and Sexuality Studies Program in the Faculty of Arts to discuss how racial identities and values shape engineering design, and in consequence have unequal impacts to different identities.

Throughout the course, we emphasized the importance of applying the material taught in the lectures to real-world scenarios, and a willingness for deep and critical reflection. For example, after the design justice lecture, we provided constructive feedback on students' preliminary designs, highlighting areas where they needed to revisit their work to better incorporate justice and inclusivity principles. An example of this feedback is provided below (Figure 4).

Green Line, Green Actions	Dynamic Ducks	Re-Decor	Garden Gang	Solar Shaders
Why do people not take transit? How would you get a better understanding of this? For example, do driver shortages and inconsistent scheduling play into it? How much of Calgary's budget is spent on transit vs. other infrastructure? How do capitalistic values influence transit funding vs. road funding? How to ensure transit feels safe for both drivers and users (without just increasing police-like enforcement which is a colonial practice)? Well sheltered bus stops could be a good resting spot for an unhoused person. Whose safety are you choosing to prioritize?	How could you learn more from Indigenous communities and/or have more applications into solving the water crisis in Indigenous communities in Canada? What are the policies around drinking water vs. sewage water, and how do those policies support or resist the matrix of domination? Can you leverage desires of upper class to create a false need for this type of work? For example, I know surfing is popular on the river. Could the water output create a surf so that the people in power would see the value of the work? (or would doing that be counter-productive?)	Your possible users were quite widely varied. Universalized designs tend to reinforce the matrix of domination. How could you work with a specific community or user? How does your design leverage the user as a co-designer? How can you see the user not just as an "assembler" but create a design that intentionally allows for hacking and modifications that are beneficial to the user? Many low-income folks rent from landlords or live in apartment buildings with strict policies (or even if not a policy, there is a hierarchical relationship). Is your design truly for everyone, or is it for middle and upper-class?	Instead of creating something new (technocentric), what already exists on campus and how could you leverage those spaces / organizations to support your ideas? If the goal is to supply the dining center with fresh food, how can they be involved and integrated in the design process? How can you better understand their actual needs and problems? The apple orchard beside Crowsnest Hall – what is there to be learned from this project? Is it well utilized or well known? Is it maintained? How could you create systems that leverage local community members to maintain what exists already?	Every car in North America has 8 parking spots. You acknowledged that this is not a good utilization of space, but what if your project results in believing that parking lots should be torn down? Who is prioritized within the matrix of domination when designing EV infrastructure (i.e. who is able to afford EVs)? Electric bikes are becoming more and more common, but there are limited spots to safely store them downtown. Why isn't this becoming more of the norm? What systems, structures, or technical reasons are preventing solar panel parking lots

Figure 4. Prompting questions for student teams to promote justice based critical thinking.

4.2.3 Leadership skills, experience, and behaviors

In addition to equipping students with knowledge, understanding and technical design skills, we placed significant emphasis on developing essential non-technical skills. These included critical thinking, teamwork, communication, presentation, report writing, and project management. Five of the nine course learning outcomes were specifically dedicated to strengthening these soft skills. By integrating these outcomes into the course structure, we cultivated the broader skill set required to navigate complex real-world challenges and work effectively in collaborative environments. The five learning outcomes are outlined below.

- *Utilize creative thinking and apply research methodologies to frame problem statements and define project goals.*
- *Demonstrate written and oral communication skills to convey sustainable design solutions.*
- *Integrate project management techniques throughout the design process.*
- *Develop team building skills in problem-solving and the design process.*
- *Enhance life-long learning skills through reflective writing.*

To enhance students' project management skills, we integrated a lecture on agile project management, alongside the introduction of various project management tools designed to help students efficiently plan, organize, and manage team dynamics. We closely monitored their progress throughout the term, providing continuous feedback and making adjustments as necessary to ensure the successful completion of their projects.

Additionally, we organized a guest lecture on "Designing a Presentation," delivered by an external expert in the field [39], which took place just before the students' final presentations. The presentation process not only focused on delivering content but also emphasized the importance of both giving and receiving constructive feedback. This approach encouraged students to embrace constructive criticism with a positive mindset, while also teaching them to recognize and value the contributions of their peers.

As this is one of their first courses involving comprehensive report writing, we invited one of our librarians to deliver a lecture on conducting a literature review. The session focused on identifying reliable and credible data, exploring various search engines and databases, and understanding academic integrity. The librarian also provided guidance on how to properly cite sources, ensuring students were equipped with the essential skills to conduct thorough and ethical research.

Furthermore, the course was designed to provide ample opportunities for collaboration, with dedicated in-class activity time, structured discussions, and focused work periods. These elements were all aimed at fostering teamwork, promoting active learning, and ensuring that students could apply their skills in a supportive, real-world context. By combining technical knowledge with essential soft skills, the course effectively supported students in both their individual and collective learning journeys.

4.3 Lessons learned from our case study

This was our first iteration of the design course and our initial attempt at integrating EOP principles into the curriculum, making it a valuable learning experience for us as instructors. One key takeaway is that we may need to modify our sprint format by setting clearer and distinct expectations of the deliverables for each sprint. When the projects were open-ended, we realized that it was essential to align assessments and deliverables with a structured rubric to evaluate their learning through the open-ended project design process. Additionally, instructors felt that more in-class work time and active learning opportunities were needed, with students working on projects in a facilitated environment rather than having full autonomy during sessions.

The co-instructors engaged in weekly reflections organized into three main sections: 'what', 'so what', and 'now what'. In the 'what' section, we described the specific activities carried out during the week, outlining what happened, the topics covered, and our experiences in implementing the weekly plan. The 'so what' section allowed us to reflect on our emotional responses, challenges faced, rewarding moments, and any difficulties encountered during the week. Lastly, the 'now what' section focused on both short-term and long-term planning, identifying the next steps and necessary adjustments to ensure the course’s continued progress and effectiveness. Throughout this process, both instructors had the opportunity to reflect individually and exchange feedback, which helped us identify shared concerns and insights during our weekly brainstorming sessions. These reflections were previously published [40]. This also served as a way to use reflection as a pedagogical learning tool, enabling us to make ongoing modifications to improve the course. If students were to follow a similar reflection process, it could add significant value to their learning experience as well.

5. Conclusion and Future Directions

This paper provided a case study exemplar of implementing the EOP Framework into a second-year engineering design course. Notably, the emphasis on systems thinking and broad range of knowledge and skills covered in the EOP Framework made it an ideal framework for supporting students in developing sustainability mindsets. The paper serves as a useful example to others with similar goals for their programs and student learning. This course has only been implemented once, and we look forward to continuously improving our approach and refining the course objectives.

The SUSE 300 course discussed in this paper is currently being implemented in its second iteration, as well as we are developing the subsequent course, SUSE 400 *Design of Sustainable Systems.* As we continue to review, reflect, and improve the implementation of EOP principles into these courses, we hope to ensure there is clear development of skills across design curriculum (SUSE 300 and SUSE 400), where we are scaffolding the EOP Framework, pushing students to the next level in the third-year design course. In the long term, we aim to assess the integration of EOP principles throughout the entire curriculum, extending beyond just the design courses. Some of these efforts are already being implemented with testing currently in progress.

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