WIP: Towards a Sustainability Practice and Ethos in a First-Year, Engineering Design Experience

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***Abstract*—This Work-in-Progress Innovative Practice paper describes a five-year sustainability intervention in an introductory engineering design course. With the aim of preparing future engineers, undergraduate engineering education is shifting environmental sustainability from the outskirts of the student experience to the center of curricular structures. For example, student engagements with environmental sustainability, referred to as "sustainability" in this paper, are moving from co-curricular experiences (e.g., Grand Challenges Scholars Program) to required coursework. Efforts to identify and inculcate sustainability-related knowledge, skills, and abilities, as well as behaviors, beliefs, and mindsets needed by engineering graduates are advancing. This transformation, while critical, can be challenging for institutions, instructors, and students alike, and results from early implementers of sustainability-related curricular experiences can inform these efforts. We present an intervention integrating ecological system design practices. Our innovative practice lies in pursuing holistic treatment of environmental sustainability in a core required introductory course enlivening disciplinary practices with student-centered pedagogy. For the purposes of preliminary assessment of this intervention, we reviewed students' engagement with sustainability during the course, their post-experience sustainability beliefs and attitudes, and the course assistants' narratives about their engagement with the students focused on sustainability. Preliminary results indicate a limited affinity for autonomous engagement with sustainability practices. Potential emerging explanations include differing perspectives between students and instructors on what constitutes impactful sustainability practice, a lack of a supporting context for establishing personal beliefs, and a lack of support for developing course-related ideas of the self and sustainability. Our experience has implications for early STEM curricula involving environmental sustainability. Requiring sustainability knowledge, skills, and abilities development ensures all students experience certain practices, but does not ensure their adoption into professional identities. We propose highlighting the course's hidden curriculum and focusing on the social architecture, establishing a more explicit community-of-practice container to enable more authentic sustainability participation.**

Keywords—sustainability education; first-year design curriculum; identity-based education; knowledge-skills-abilities

I. Motivation and Context

As the world responds to climate change with technological solutions, design engineers have the opportunity and responsibility to address many environmental sustainability challenges [1]. With the aim of preparing future engineers, undergraduate engineering education is transforming by shifting sustainability from the outskirts of the student experience to the center of curricular structures. These critical shifts move sustainability from being elective to integrated within the holistic curriculum, ensuring engagement of more students [2], [3]. Furthermore, efforts to identify and inculcate sustainability-related knowledge, skills, abilities (KSAs), and behaviors, as well as beliefs and mindsets needed by engineering graduates are advancing (e.g., Engineering for One Planet) [4].

Integrating sustainability into existing engineering curricula can strain institutions' and instructors' already limited bandwidths for curriculum development [5], [6], [7]. Instructors may not be able to redesign fully integrated curricula with multiple touchpoints to sustainability, which may be the most effective means of educating students [8]. To that end, many programs have enhanced their sustainability offerings through elective courses or through a single module or unit within a required course. This approach means that not all engineering students are exposed to sustainability and do not engage holistically. In these cases, undergraduate programs may fall short of preparing all graduates to engage with sustainable engineering and strategies in their professional practices, qualities necessary to address the green jobs gap society currently faces [9]. This approach may also signal to students that sustainability is optional or separate from other engineering topics that are given a more central role [10].

From the student perspective, it may be challenging to fully step into the role of a sustainable design engineer. This may be particularly true for undergraduate students who have not yet begun exploring their engineering identity [11]. Students may have been drawn to engineering for reasons other than enhancing environmental sustainability [12], [13]. They may not realize the impact that engineering has on the environment, and therefore not appreciate the potential impact of their engineering decisions. Even students who prioritize sustainability may not feel they can have a large impact. As educators, we aim to demonstrate the link between engineering and sustainability, that students can and should hold sustainability as one of their many priorities, and that their engineering actions can have a positive impact on the environment.

Given the challenges related to implementing sustainability-related curricular experience in undergraduate programs, this paper details our efforts in this regard. Results from our early implementation can inform ongoing efforts to integrate sustainability into undergraduate engineering programs.

II. Context of the Practice

Our intervention takes place at Olin College of Engineering, a small, residential, private college offering only engineering degrees. Olin places a strong emphasis on impact-centered learning with a sustainability focus. We adapted a required first-semester introduction to engineering design course, Design Nature (DN) [14], [15]. This is the first course in Olin's design stream that includes six or more courses over the four-year degree program [16]. DN combines disciplinary design practices with student-centered pedagogy.

From a disciplinary perspective, students develop bioinspired ideas into functional prototypes, focusing on the general mindsets, behaviors, and methods that shape the practice of engineering design. Learning is scaffolded by a seven-week individual project ("the hopper project") followed by a seven-week team project ("the play project") with four to five students per team, both spanning proposal-to-prototype design phases. In this paper, we focus on the hopper project, where students are tasked with designing and building jumping mechanisms from a predefined kit of materials, a project detailed in Section III.

Studio-based [17], [18] and project-based learning approaches [19], [20] are used to support an experiential learning environment cultivating knowing through practice and dialog with materials. Development of self-regulated learning [21], [22] is facilitated through regular assignments that reduce the planning, monitoring, and evaluation load presented to new design learners in an open-ended design challenge (this scaffolding is substantially reduced during the second project). The individual project addresses variation in preparedness, including due to underinvestment. Addressing this variation is critical before placing students in teaming situations where it can otherwise lead to differential learning outcomes due to task orientation dominating [23]. Attention is given to supporting students' basic psychological needs (i.e., competency, autonomy, and relatedness) to facilitate shifts toward intrinsic motivation [24] and developing students' design-oriented behaviors and mindsets (e.g., comfort with ambiguity, prototyping to learn, variation, and iteration).

III. The Practice

Over the past five years, we have been incorporating environmental sustainability in an introductory engineering design course by integrating ecological system design practices at multiple levels. This approach incorporates a subset of sustainability concepts, including biomimicry, circularity, dematerialization, and impact assessment. The intervention includes the following curricular elements:

- Direction to take inspiration from nature,
- Prompt to consider environmental impact goals,
- Instruction on sustainable design strategies,
- Embodied carbon factors for kit materials,
- Calculation of total embodied carbon of designs,
- A class-wide, closed-loop system for all materials, and
- Field sketching and reading papers on biomechanics.

Broadly, the design brief asks students to take inspiration from nature to develop hoppers that mimic the structure-function of primarily insect hopping behavior in nature [25]. Students engage in a studio activity that explores principles of biomimicry, make field sketches of hopping insects outdoors, and read scientific papers (and summaries thereof) on the biomechanics of hopping insects, specifically froghoppers and click beetles. These readings also enable a review of physics principles through a studio activity where students are asked to elucidate the physics of the insects' behaviors.

We support student autonomy around design goal formation and sustainable design strategies. Students are prompted but not required to consider including an environmental impact dimension to their goal along with other success metrics (e.g., performance, aesthetics). Additionally, students receive a learning module introducing several sustainable design strategies they could consider, with which they are invited to engage during an in-studio activity.

We provide a materials kit to enable students' autonomy while scaffolding a rich yet manageable design space constrained to prototyping materials and associated fabrication methods that are accessible and typical in engineering. The kit contents span a range of specific environmental impacts (kg CO_2eq/kg) and affords the possibility of mechanical failures, which are addressed through just-in-time instruction (e.g., lectures and experiments on stress analysis and failure modes).

We instruct students to estimate the material impact of their final prototype with a single-indicator lifecycle assessment and to report this environmental impact along with their physics-based performance estimates. The cradle-to-gate single factor impacts in the form of embodied carbon (CO_2eq) are provided for the kit materials to enable these calculations.

Furthermore, we model and enable systemic sustainable design practice by making the entire first project a class-wide closed-loop system. All materials are recovered for reuse at the end of the project or are appropriately recycled with no trash generated. Students are required to design for participation in this system, meaning, for example, they cannot use hot glue to create monstrous hybrids that prevent material recovery.

IV. Preliminary Assessment and Insights

We have begun evaluating the intervention with three approaches, detailed in the following subsections. Overall, the preliminary results indicate some affinity for students' autonomous engagement with sustainability practices. Data were collected during the 2024 Spring term, recruiting the 102 participants in the Fall 2023 offering.

A. Students' Self-Defined Goals: Sustainability Dimension

An early milestone in the project asks students to set a design goal that defines success for their individual hopper. The prompt invites students to include a bioinspiration element and a personal element. The latter includes suggestions of environmental impact, aesthetics, and performance. To assess the influence of providing students with the choice to engage in sustainability, we evaluated how many goals included an explicit reference to such a dimension. Of the 102 recruited students, 20 gave permission to use their assignment as a data source for this assessment. Of those, five or 25% incorporated environmental impact or another aspect of sustainability in their goal statement, which could have been influenced by selection bias. To contextualize these responses, in an *Inside Higher Ed* and College Pulse survey, 14% and 32% of U.S. college students respectively reported "Yes, many times" and "Yes, a few times" when asked in 2022 "Regardless of your major, have you made any choices to pursue topics related to sustainability in your coursework when possible?" [26].

In the absence of additional data, we can hypothesize higher engagement with the sustainability dimension in students' self-defined goal statements would require an increase in accessibility, expectations, or interest. Alternatively, we might argue that because the invitation to commit to a sustainability consideration came at the beginning of the course before confidence in environmental impact analysis was established, the students may be reluctant to engage in the topic.

B. Student's Perceptions of the Relationship between Sustainability, Engineering, and DN

To understand how and why students engaged with sustainability in DN, we surveyed them one semester after the course. Open-ended questions elicited students' thoughts about the relationship between engineering and sustainability, how their experience in DN influenced this perspective, how they engaged with sustainability as students in DN, and their choice to include a sustainability dimension in their goal statement.

Nine students responded to the survey, commenting most frequently on the embodied carbon assignment and material use. Each of the sustainability intervention elements described in Section III was reflected on by at least one student, suggesting that all elements may have had some impact.

Open-ended responses provided insights into why students chose to engage in sustainability. For example, one student said they chose Olin specifically to pursue sustainability and "[found] it imperative to try to engage with some form of sustainability in all of [their] projects when the project guidelines allow." Because Olin's marketing to prospective students includes details about sustainability-related courses and degree programs, this comment suggests that sustainability-focused students may self-select to attend Olin. For these students, the described interventions allow for the option to engage with sustainability.

However, in other cases, the sustainability-focused project scaffolding did not lead to engagement with this topic. One student claimed that sustainability was critical to engineering but did not include a sustainability dimension in their goal statement, commenting, "I did not see how any design alterations to my hopper would have any meaningful impact on the environment." Another agreed, noting that the "project is so small scale." Further investigation of this perspective and its prevalence among first-year students may shed light on the underlying reasons for students' not seeing how small-scale projects early in their engineering experiences can have large-scale impacts later in their careers. We further hypothesize that many of today's first-year engineering students' identities do not a priori include a sustainability dimension, and it is incumbent upon their early curricular engagements to have this dimension explicitly articulated and engaged.

Of interest to this preliminary assessment are comments from several students that imply they believed sustainability was at odds with other success metrics. For example, one student wrote, "Other ideas such as art and design interested me more [than sustainability]." Another student shared, "I wanted to make something fun that would jump high, not something environmental," while yet another one stated that the project "lets people who are really passionate [about sustainability] explore this passion without restricting students who aren't." The course aims to show students that sustainability is a core design expectation and not just one of many engineering performance metrics, but these comments suggest that objective was not met for multiple students. Providing flexibility in addressing sustainability as a means of enabling intrinsic motivation could respond to students' diverse values.

C. Near-Peer Students' Observations

To understand the student experience from a perspective other than their own, we solicited the insights of upper-level course assistants (CAs), who had taken DN in prior years. These individuals decide to return to the DN community as near-peer mentors to the current students. As fellow undergraduates, they socialize course content, including sustainability topics. As part of their role in DN, the CAs meet weekly with course instructors and attend class sessions but do not receive formal education training. CAs have a unique perspective to offer this assessment, so we asked them to describe their conversations with DN students about sustainability and any observations they had of students engaging with sustainability.

Of the 18 recruited CAs, nine responded. Their responses showed that they had fewer sustainability-related conversations than expected. CAs did not comment on the bio-inspired nature of the projects and commented infrequently on the goal statements. Concurring with student responses, CA observations focused on materials use and the embodied carbon assignment.

The embodied carbon assignment had a large positive impact on one CA. They reflected on how it played into their journey as a sustainable engineer. Before taking DN, this CA said they "had never thought of environmental impact as quantifiable before… [and] working with embodied carbon estimates made the process feel more like an exact science." After being a DN student in a prior year, this CA had a summer internship quantifying environmental impact data. Then, as a CA, they described working with a student on the embodied carbon assignment and reflecting, "Until this moment, I had forgotten how new the content felt as a student." They raised an important point that the proposed sustainability intervention may be the first time students face their role in society as it relates to engineering and sustainability. Grappling with this large question may require multiple touchpoints, like this CA had, to fully influence students in the ways we were expecting.

Two CAs discussed the same intervention—the embodied carbon assignment—and thought it might oversimplify the relationship between sustainability and engineering. They commented that the assignment "seemed to boil the idea of embodied carbon down to math," and that their perceived value of that assignment was related "more for the math aspect than the environmental aspect." Engineers often find ways to simplify complex systems to concrete, easy-to-apply mathematical models. Further explanation of how these simple models can be strong predictors of more complex systems could improve students' responses to this intervention.

Separately, we were surprised by one CA comment about the structured nature of the hopper project—restricting materials and requiring the embodied carbon assignment—limiting students' abilities to independently engage with sustainability. They noted, "There is no autonomy in the [student's] decision to be sustainable... Removing the student from that decision greatly reduces the possibility of intrinsic motivation toward sustainability." This was an interesting comment to us because these intervention elements and others were explicitly designed to give students choices. Students have the choice of which kit materials, and therefore how much embodied carbon, to use. Students have a great degree of autonomy in how they define their success metrics and where they seek bio-inspiration. This CA comment suggests it is not clear to students or CAs the intentional design freedoms designed into their projects.

In another category, CA responses suggest that they may not fully appreciate the extent of their influence in developing students' perspectives on sustainability. One CA, who thought that engineering and sustainability were closely tied together, said they "[didn't] feel [they] influenced any of the student's opinions on environmental sustainability." Another commented that they were not sure if they had "a full fledged conversation about sustainability…but did make sure to stress the importance of it if it ever came up in conversation." These responses highlight the importance of engaging CAs throughout the educational experience in conversation about their relationship to and identification with engineering and sustainability and how those aspects of their identity may affect the way in which they engage and indeed support DN students' development.

V. Looking Forward

The need for graduates to be prepared for and participate in realizing a sustainable world gives rise to sustainability learning objectives for courses such as introductions to engineering design. One important goal in these environments should be for students to understand there is a more responsible way to practice design [27] that includes addressing environmental and social impact, to see design processes without this aspect as undesirable, even unacceptable, and to question participating in processes of this kind, a form of design refusal [28].

Achieving this outcome necessitates student awareness of and experience with sustainability KSAs, increasing confidence as well as affording graduates expertise power. However, based on our experience, we believe that identifying and requiring sustainability KSAs alone is not enough for achievement of this outcome, although doing so is possibly the more common educational practice. While we see practicing sustainability KSAs within a studio-based design pedagogy as tacitly establishing norms of good design practice through knowing in practice [17], we now understand this to be a too-hidden curriculum that we need to make explicit [18], [27].

This goal involves a larger moral frame, and we see the potential for a social learning theory approach to identity development to engage this broader frame [29]. It is akin to expecting graduates to adhere to ethical norms of practice in professional contexts, which we know is highly dependent on the permissiveness of the social signaling present [30]. We can imagine students will need a learning community of practice to form and anchor their beliefs, reinforce their responsibility to public welfare [27], and provide for legitimation of their professional sustainability practice. The students would also likely need that community to be change-oriented, directly addressing current professional social signaling and entering into those signals.

We see a possibility to focus on the social architecture of the course establishing a more explicit community of practice container. We intend to introduce social signaling and authentic participation around engaging sustainability and formation of engineering identities. There are many possibilities, such as explicitly establishing norms, modeling values and choices, enabling student responsibility for the repertoire, identifying tactics to advocate for sustainability in professional contexts, and engaging students in storying their narrative of self vis-a-vis sustainability [31]. The positionality of the CAs in the middle ground of the community of practice suggests the possibility of reinforcing their role and bridging it beyond the classroom. As such, our next steps might include:

- Making learning of normative roles and responsibilities a part of the curricular content,
- Showing diverse practitioners making sustainability commitments and choices in their design work,
- Sharing student-generated strategies for sustainable design moves and passing these on to future students,
- Asking students to reflect on how they could relate sustainability to their idea of themselves as an engineer,
- Role-playing tactics for raising sustainability dimensions of design practice in new professional contexts, and
- Having CAs discuss with each student the sustainability aspects of their design choices.

We are aware that the social context of the class is reified by the authenticity of the community of practice in which we are mutually engaged. Classroom experiences do not necessarily create the conditions for students to be authentic participants [29]. Based on our experience to date, these conditions are not sufficiently met by providing a choice between options within the repertoire, such as between sustainable design strategies.

Acknowledgment

The authors thank the students and course assistants of Design Nature for their participation in this assessment and the many instructors, especially Theresa Edmonds, who contributed significantly to this intervention with the second author, as well as Olin College for supporting the work on this intervention.

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