Developing a Sustainability Mindset in First-Year Engineering Students Through an Immersive Summer Camp Experience

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Abstract

Sustainability has become a central priority in engineering education, requiring future engineers to integrate environmental, social, and economic considerations into engineering decision-making. Developing a sustainability mindset—defined as the integration of knowledge, skills, attitudes, and behaviors that support sustainable engineering practice—is increasingly recognized as essential for addressing complex global challenges. This study examines the design, implementation, and evaluation of a one-week immersive summer camp developed as an early intervention within a Sustainability Engineering minor at the University of Puerto Rico, Mayagüez, which is a public, Hispanic-Serving Institution. This study contributes design-informed evidence on how early short-duration immersive experiences can support the development of sustainability mindset at the beginning of engineering pathways for students.

The camp was implemented across two cohorts with iterative program redesign. The 2023 camp emphasized reflection-based activities, while the 2024 camp incorporated applied, design-centered team projects to strengthen real-world problem-solving and implementation skills. Using a qualitative research approach, this study analyzes pre- and post-camp open-ended survey responses administered in both English and Spanish to examine changes in first-year engineering students' sustainability-related knowledge, skills, attitudes, and behaviors.

Survey responses from 23 participants were analyzed using grounded theory and constant-comparison methods to identify emergent themes. Findings indicate that students' understanding of sustainability evolved from primarily environmental framings toward more integrated social, economic, and ecological perspectives. Participants also reported increased awareness of professional responsibility, growth in collaboration and problem-solving skills, and greater intention to incorporate sustainability considerations into personal, academic, and future professional contexts. Notably, cross-cohort analysis highlights how applied, design-centered activities prompted more action-oriented sustainability thinking compared to reflection-only approaches, offering transferable insights for program design.

Overall, the results suggest that short-term immersive learning experiences can support early sustainability mindset development among first-year engineering students and provide actionable guidance for the intentional design of sustainability-focused experiential learning environments in engineering education.

Keywords sustainability mindset; engineering education; immersive experiential learning; first-year engineering students; qualitative research; sustainability education; co-curricular learning

Introduction

Engineering education is increasingly being shaped by the expectation that graduates will be prepared to address complex challenges that extend well beyond technical problem solving. Issues such as climate change, resource management, infrastructure resilience, and social equity require engineers to consider environmental, social, and economic dimensions simultaneously. In this context, the concept of a sustainability mindset has gained prominence, emphasizing how engineers frame problems, weigh tradeoffs, and make decisions with long-term societal consequences in mind [1, 2].

National and international organizations have consistently highlighted the role of higher education in preparing engineers for these responsibilities. Reports from the National Academies of Sciences, Engineering, and Medicine call for engineering programs to move beyond compartmentalized instruction and instead foster systems thinking, ethical reasoning, and real-world problem engagement throughout the curriculum [3, 4]. Similarly, UNESCO frames education for sustainable development as essential for equipping students with the competencies needed to contribute meaningfully to sustainable societies [5].

Within engineering education, several frameworks have emerged to guide the integration of sustainability into learning experiences. The Engineering for One Planet (EOP) Framework provides a structured approach for embedding sustainability outcomes across both curricular and co-curricular contexts, with particular emphasis on systems thinking, stakeholder awareness, lifecycle considerations, and application of sustainability principles in authentic engineering settings [6]. A central premise of these efforts is that sustainability should be introduced early and reinforced over time so that it becomes an integral part of how students understand engineering practice.

Despite this growing consensus, sustainability instruction in many engineering programs continues to appear later in the curriculum, often through upper-division courses or specialized electives [7]. When sustainability is introduced only after students have already internalized disciplinary norms and problem-solving approaches, opportunities for early mindset development may be limited. Early immersive learning experiences offer one potential strategy for addressing this gap by engaging students with sustainability challenges before their conceptions of engineering practice are fully established.

This paper examines how first-year engineering students participating in a Sustainability Engineering program described changes in their sustainability-related knowledge, skills, attitudes, and behaviors following participation in a one-week immersive summer camp. Using a qualitative research approach, the study explores how students articulated their understanding of sustainability before and after the experience, as well as how they reflected on the role of sustainability in their future academic and professional trajectories.

The research question guiding this study is: *How does participation in an immersive summer camp influence the development of a sustainability mindset in first-year engineering students, particularly with respect to their knowledge, skills, attitudes, and behaviors related to sustainability?*

To address this question, the study analyzes open-ended pre- and post-camp survey responses administered in both English and Spanish. Offering surveys in both languages allowed students to express their perspectives without language constraints and supported more inclusive participation. In addition, the study examines the effects of iterative program design by comparing two camp formats: a reflection-focused model implemented in 2023 and a more applied, design-centered model implemented in 2024.

Together, these analyzes provide insight into how immersive experiential learning environments may support early sustainability mindset development and inform the design of sustainability-focused learning experiences in engineering education.

Background and Justification

Preparing engineers to address sustainability challenges requires educational approaches that acknowledge the complexity and interconnected nature of environmental, social, and economic systems. Engineering decisions frequently involve competing constraints, uncertainty, and long-term consequences, making sustainability a fundamentally integrative challenge rather than a purely technical one [1, 2]. As a result, sustainability education increasingly emphasizes the development of ways of thinking and acting that support responsible and context-aware engineering practice.

Policy reports and educational frameworks have reinforced the importance of embedding sustainability throughout engineering education. The National Academies of Sciences, Engineering, and Medicine emphasize that sustainability-related learning should be woven across curricula through opportunities that engage students in systems-level reasoning, ethical reflection, and real-world problem solving [3, 4]. UNESCO similarly underscores the role of higher education in cultivating competencies such as critical thinking, responsibility, and action-oriented engagement in support of sustainable development goals [5]. Together, these perspectives suggest that sustainability learning is most effective when it is treated as a core element of professional preparation rather than as an isolated topic.

Within engineering education, the Engineering for One Planet (EOP) Framework offers guidance for translating these broader goals into educational practice [6]. The framework identifies sustainability outcomes related to systems thinking, stakeholder engagement, lifecycle awareness, and application of sustainability principles in authentic contexts. Notably, EOP highlights experiential and applied learning as important mechanisms for supporting these outcomes, providing a useful lens for examining student learning in immersive educational environments.

Although the importance of sustainability integration is widely acknowledged, many engineering programs still introduce sustainability concepts later in students' academic pathways [7]. This timing may limit the extent to which sustainability becomes embedded in students' developing engineering identities. Prior research in engineering education suggests that early experiences play a significant role in shaping students' perceptions of the profession, their values, and their sense of responsibility as engineers [8]. Early interventions may therefore be particularly influential in normalizing sustainability as part of everyday engineering decision-making.

Experiential learning theory provides additional support for early, immersive approaches. Learning environments that emphasize active engagement, collaboration, and real-world application have been shown to support deeper learning and integration of theory and practice [9, 10]. In sustainability education, experiential and project-based learning can help students connect abstract concepts to tangible challenges, supporting learning across cognitive, affective, and behavioral dimensions. Design-centered experiences, in particular, require students to grapple with constraints, tradeoffs, and implementation considerations that mirror professional engineering practice [11].

Despite this body of work, relatively little research has examined how short-duration immersive experiences—such as pre-matriculation or early undergraduate summer programs—contribute to sustainability mindset development. Much of the existing literature focuses on semester-long courses or capstone projects, leaving open questions about how early, high-intensity experiences might influence students' understanding of sustainability and their subsequent learning trajectories.

The present study addresses this gap by examining sustainability mindset development among first-year engineering students participating in a one-week immersive summer camp associated with a Sustainability Engineering program. Using qualitative analysis of open-ended pre- and post-camp survey responses, the study explores how students described changes in sustainability-related knowledge, skills, attitudes, and behaviors following the experience. In addition, the study considers how iterative changes in program design—specifically the shift from reflection-focused activities to applied, design-centered projects—may shape students' sustainability learning experiences.

By situating the summer camp within established sustainability education frameworks and experiential learning literature, this work provides a foundation for interpreting the qualitative findings and for developing implications related to program design, assessment, and early integration of sustainability in engineering education.

Literature Review

Sustainability in Engineering Education. Sustainability has emerged as a central theme across multiple disciplines, including engineering, attracting increasing attention from educators, students, and industry stakeholders. Sustainable development is commonly defined as meeting present needs without compromising the ability of future generations to meet their own needs, emphasizing the interconnected pillars of environmental protection, social responsibility, and economic viability [1]. In engineering education, sustainability is increasingly understood not only as technical content, but also as a professional orientation that influences how engineers define problems, evaluate tradeoffs, and justify design decisions.

Prior literature highlights substantial overlap between sustainability education and broader discussions of professional responsibility in engineering. Engineers are expected to consider long-term societal impacts, ethical implications, and stakeholder perspectives when developing solutions to complex problems. As a result, sustainability learning has increasingly been framed as multi-dimensional, extending beyond knowledge acquisition to include skills, attitudes, and behaviors

associated with responsible engineering practice [2, 7].

This multidimensional framing aligns with emerging models of sustainability engineering that position sustainability as a foundational lens for engineering education. Santiago-Román et al. propose a transdisciplinary, learner-centered, and DEI-focused paradigm for sustainability engineering, emphasizing that sustainability education should explicitly engage students with social context, equity considerations, and real-world constraints [12]. This work provides a conceptual foundation for examining sustainability learning as an integrated process that includes technical reasoning alongside social responsibility and justice-oriented considerations.

Sustainability Mindset and Student Development. Within this broader framing, the concept of a sustainability mindset has gained traction as a way to examine how students internalize sustainability-related ways of thinking. Sustainability mindset encompasses how students understand sustainability concepts, how they value sustainability in relation to engineering practice, and how they anticipate acting on these values in academic, personal, and professional contexts. In a prior work, a general framework was established to capture sustainability mindset under a general umbrella of knowledge, skills, attitudes, and behaviors ("KSAB") [13]. Other research further suggests that sustainability mindset development involves shifts in perspective rather than discrete content mastery, making it particularly relevant for early-stage educational interventions [2].

Research in engineering education has increasingly emphasized the importance of examining sustainability learning through holistic lenses that include attitudes and behavioral intentions. Bielefeldt notes that sustainability integration is most meaningful when students are encouraged to reflect on ethical responsibility, societal impact, and the role of engineers in addressing sustainability challenges [7]. These dimensions are difficult to capture through traditional assessments but are central to understanding how students conceptualize sustainability.

Recent work has further connected sustainability mindset development with principles of diversity, equity, inclusion, and justice. Colón-Rivera et al. examine how first-year engineering students engage with DEIJ principles through sustainability-focused learning experiences, demonstrating that sustainability mindset development can serve as a pathway for introducing social justice considerations in early engineering education [14]. This work is particularly relevant to the present study, as it highlights how early sustainability interventions may influence not only students' technical perspectives but also their understanding of equity, responsibility, and community impact—dimensions reflected in the qualitative results reported later in this article.

Experiential and Immersive Learning Environments. Experiential learning environments are widely recognized as effective for supporting deep learning, professional identity development, and integration of theory and practice. Experiential learning theory emphasizes the role of active engagement, reflection, and application in supporting meaningful learning [9]. In engineering education, active and experiential learning approaches have been associated with improved engagement, motivation, and conceptual understanding [10].

Immersive learning environments, including summer camps and short-duration intensive programs, are often used as early interventions to introduce students to engineering practices and professional

norms. Although such programs are limited in duration, research suggests that immersive experiences can influence students' confidence, interest, and perceptions of engineering when activities are intentionally designed and aligned with real-world contexts [15]. These environments provide concentrated opportunities for students to engage with complex problems, collaborate with peers, and reflect on their learning within a short period of time.

For sustainability education specifically, immersive experiences offer opportunities to connect abstract sustainability concepts to tangible challenges. Design-centered and project-based activities require students to consider constraints, tradeoffs, and implementation decisions that mirror professional engineering practice [11]. This alignment is particularly relevant for sustainability learning, where engineers must balance competing environmental, social, and economic considerations. Prior research suggests that applied learning environments may support stronger action-oriented thinking than reflection-only activities, especially when students are asked to justify decisions and consider societal impacts [16].

Assessment of Sustainability Learning. Assessing sustainability learning presents ongoing challenges due to the multidimensional and often developmental nature of sustainability mindset. Traditional assessment approaches in engineering education have tended to focus on measurable knowledge and skills, while sustainability learning also involves shifts in values, perspectives, and behavioral intentions [17]. These shifts may emerge gradually and are not always immediately observable following short interventions.

Qualitative assessment approaches, including open-ended surveys and reflective prompts, are commonly used to examine learning in exploratory and immersive educational settings. Such methods allow students to articulate their understanding of sustainability in their own words and provide insight into how students connect sustainability concepts to their personal experiences and future goals [18]. These approaches are particularly appropriate for early-stage or pilot interventions, where the goal is to identify emerging patterns in learning rather than to establish causal relationships.

Taken together, this literature supports the use of immersive summer camps as a theoretically grounded context for examining sustainability mindset development in engineering students. It also provides a foundation for interpreting qualitative shifts in students' sustainability-related knowledge, skills, attitudes, and behaviors, as well as for deriving implications related to the design of sustainability-focused experiential learning environments. Figure 1 summarizes the study's conceptual framing of sustainability mindset development through immersive experiential learning, organized using KSAB lenses [13] to guide analysis and reporting.

Methods

This study used a qualitative, pre–post design to examine how first-year engineering students articulated sustainability-related knowledge, skills, attitudes, and behaviors following participation in a one-week immersive Sustainability Engineering summer camp. The camp served as an early intervention within a Sustainability Engineering minor at a Hispanic-Serving Institution and was

implemented across two cohorts (2023 and 2024) with intentional iterative redesign.

Study Context and Program Description. The Sustainability Engineering summer camp was designed to introduce incoming first-year engineering students to sustainability concepts and practices through an immersive, co-curricular experience prior to the start of the academic semester. The camp emphasized (a) broad sustainability framing across environmental, social, and economic dimensions; (b) collaborative engagement; and (c) engineering-relevant problem solving.

Two camp formats were implemented. The 2023 camp emphasized reflection-based activities (e.g., guided discussion, structured reflection prompts, conceptual exploration). The 2024 camp incorporated applied, design-centered team projects intended to strengthen real-world problem framing, solution development, and implementation-oriented reasoning. These formats reflect program iteration rather than an experimental treatment comparison; therefore, any cross-cohort differences are interpreted descriptively. Figure 1 summarizes the key features of the two summer camp formats and highlights elements that remained consistent across cohorts.

Participants and Recruitment. Participants were incoming first-year engineering students who enrolled in the Sustainability Engineering summer camp through the Sustainability Engineering minor program at the University of Puerto Rico, Mayagüez. Students participated as part of the program's early engagement activities. The combined sample across cohorts included 23 participants, including 15 men and 8 women and from several different engineering programs (6 Mechanical, 5 Chemical, 5 Industrial, 5 Electrical/Computer, and 2 from Civil).

Program-specific recruitment details: Recruitment for the camp was conducted with help of the outreach office in the College of Engineering. First, an email was sent to all newly admitted students to an engineering program early in the Spring semester announcing the opportunity. A similar email was sent to a network of more than 200 local and regional high school teachers, asking them to promote the opportunity among their students. Second, these emails scheduled virtual orientation sessions to allow students, parents, and teachers to hear directly from the project team and to ask questions. For the first cohort, the virtual orientation attracted approximately one dozen teachers; for the second cohort, a total of 80 students, parents, and teachers attended the virtual orientation.

Interested students were then required to complete an application that included demographic and contact information; high school transcript; letters of recommendation from at least two teachers or counselors (at least one from a STEM teacher); and a resume. The application form also inquired if the applicant already had earned advanced placement credit or was scheduled to take an advanced placement test. The application did not request an essay, due to the possibility that essays might be written with undue external assistance. However, once the application deadline had closed, a trained undergraduate assistant conducted a phone interview with a selected subset of strong candidates based on the strength of the transcript, letters, and resume. This was done in order to hear from the student directly regarding their interest, ideas, and prior experience related to sustainability.

The ultimate selection was based the prior factors plus performance on the phone interview. Finally, a strict requirement was that students must have completed a college level course prior to the start

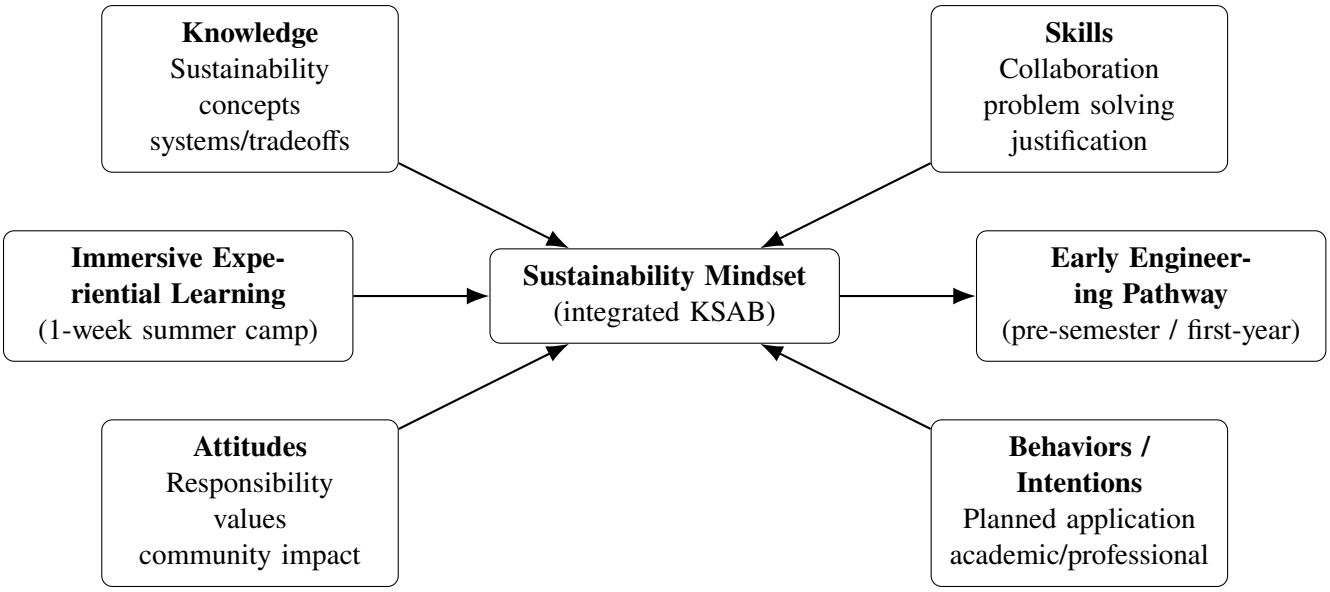

Figure 1: Conceptual framework for early sustainability mindset development through an immersive experiential learning intervention, organized using KSAB lenses.

Table 1: Overview of Sustainability Engineering summer camp design across cohorts.

Feature	2023 Cohort (Reflection-Focused)	2024 Cohort (Applied, Design-Centered)
Primary emphasis	Conceptual understanding and awareness of sustainability	Application of sustainability principles through design-centered projects
Learning activities	Guided discussions, structured reflection prompts, conceptual exploration	Team-based design projects, solution development, feasibility considerations
Student engagement	Individual and group reflection	Collaborative, problem-solving-oriented teamwork
Sustainability focus	Perspective shifts and conceptual framing	Action-oriented sustainability reasoning and implementation considerations
Interpretive use	Program iteration (not treatment comparison)	Program iteration (not treatment comparison)

of the summer camp in July; this was to allow them to have space in their schedules during their first semester to take a sustainability-related course. In some cases, strong candidates were given conditional acceptance if they enrolled in a college course during the first summer session, prior to the start of the camp

Data Sources and Instruments. Data were collected through pre- and post-camp surveys consisting primarily of open-ended prompts. Surveys were administered in both English and Spanish to support inclusive participation and to allow students to express their perspectives without language constraints.

Open-ended items elicited students' definitions of sustainability, perceptions of the role of engineers in sustainability challenges, and reflections related to sustainability-oriented practices and intentions (e.g., academic and professional application). The pre-survey was administered on the first day, prior to camp activities, and the post-survey was administered in the final day, after concluding activities. Participation in the surveys was optional; responses were de-identified prior to analysis.

Ethics and Human Subjects Considerations. This study followed institutional protocols for research involving human participants. Students were informed that survey responses would be used for program evaluation and research purposes, and confidentiality procedures were followed.

Analytic Approach. Survey responses were analyzed qualitatively using grounded theory and constant-comparison methods, consistent with the approach described in the Abstract. Analysis proceeded iteratively to identify emergent themes within and across participants' pre- and post-survey responses.

To support coherence and alignment with sustainability mindset framing, emergent themes were organized using four analytic lenses: knowledge, skills, attitudes, and behaviors (KSAB). These lenses were used as interpretive organizers rather than rigid coding bins; individual responses frequently reflected multiple dimensions simultaneously. The overall data collection and qualitative analysis workflow is summarized in Table 2.

Coding Procedures and Trustworthiness. Analysis followed a structured, iterative process:

- **Initial familiarization:** The research team reviewed all responses to understand breadth, language patterns, and recurring ideas.
- **Open coding:** Responses were coded inductively to capture key ideas expressed in students' own terms.
- **Constant comparison:** Codes were compared within and across pre/post responses and across cohorts to refine categories and identify patterns of change in articulation.
- **Theme development:** Related codes were grouped into emergent themes and then organized under KSAB lenses for reporting.

Coding was conducted by multiple coders. The team met to discuss code definitions, resolve discrepancies through discussion, and refine the codebook iteratively. Trustworthiness was supported through peer debriefing, and interpretation remained grounded in participants' language.

Cross-Cohort Comparison Logic. Although the study was not designed as an experimental comparison, the existence of two cohorts with different camp structures allowed descriptive examination of how students' post-camp articulations differed across formats. Cross-cohort observations are presented as design-informed insights rather than causal claims. The goal is to inform educators about how design choices in immersive sustainability experiences may shape the ways students express sustainability-related learning and intentions.

Limitations of the Methodological Design. This study examines short-term changes in student articulation following a one-week experience and relies on open-ended self-report data. Findings are context-specific, based on a small sample within a particular institutional program, and are not intended to be generalized broadly. The results are therefore presented as qualitative evidence of emergent sustainability mindset development and as guidance for future program design and research.

Results

This section presents qualitative findings from analysis of pre- and post-camp open-ended survey responses. Results are organized around four analytic dimensions—knowledge, skills, attitudes, and behaviors—to describe how students articulated their understanding of sustainability and the role of engineers before and after participation in the immersive summer camp. These dimensions are used as interpretive lenses rather than discrete categories, and individual responses often reflected multiple dimensions simultaneously. Table 3 provides a synthesized summary of the emergent themes reported across the KSAB lenses.

Sustainability-Related Knowledge. Across cohorts, students' post-camp responses reflected a broader and more integrated understanding of sustainability compared to their pre-camp responses. Prior to the camp, students often described sustainability primarily in environmental terms, focusing on resource conservation, pollution reduction, or environmental protection. Following the immersive experience, many students articulated sustainability as a multidimensional concept that also included social, economic, and community considerations.

Post-camp responses more frequently referenced systems-level thinking, including connections between engineering decisions and their broader impacts. Students described sustainability as involving tradeoffs among competing priorities and constraints, rather than as a set of isolated environmental practices. These shifts suggest that students began to conceptualize sustainability as an inherent aspect of engineering problem solving rather than as an external requirement or add-on.

Sustainability-Related Skills. In describing skills associated with sustainability, students' post-camp responses emphasized collaboration, communication, and problem-solving in applied con-

Table 2: Qualitative data collection and analysis workflow.

Stage	Description
Pre-camp survey	Open-ended survey administered prior to the immersive experience to capture baseline sustainability-related knowledge, attitudes, and perspectives.
Immersive camp experience	One-week Sustainability Engineering summer camp involving reflection-based or applied, design-centered activities depending on cohort.
Post-camp survey	Open-ended survey administered at the conclusion of the camp to capture changes in articulation of sustainability-related knowledge, skills, attitudes, and behaviors.
Open coding	Inductive coding of student responses to identify key ideas expressed in participants' own words.
Constant comparison	Iterative comparison of codes across pre/post responses and across cohorts to identify patterns and changes in articulation.
Theme organization	Emergent themes organized using knowledge, skills, attitudes, and behaviors (KSAB) lenses for reporting and interpretation.

Table 3: Summary of emergent themes organized by KSAB lenses (illustrative categories drawn from qualitative analysis).

KSAB Lens	Representative emergent themes (as articulated in student responses)
Knowledge	Broader, multidimensional sustainability framing; systems-level connections; recognition of tradeoffs and constraints
Skills	Collaboration and communication; applied problem solving; ability to propose and justify sustainability-informed solutions
Attitudes	Increased sense of professional responsibility; attention to community impact; awareness of social implications of engineering decisions
Behaviors / Intentions	Intentions to apply sustainability in coursework and future practice; commitment to consider sustainability in decision-making; planned personal actions

texts. Students frequently referred to working with peers to explore sustainability challenges and to considering multiple perspectives when discussing potential solutions.

Students in the cohort that participated in the applied, design-centered camp structure more often described skills related to proposing, evaluating, and justifying potential solutions to sustainability challenges. These descriptions included references to considering constraints, feasibility, and real-world applicability. In contrast, responses from the reflection-focused camp more often emphasized discussion and conceptual understanding. These differences are reported descriptively and reflect variations in how students articulated their learning rather than comparative effectiveness.

Sustainability-Related Attitudes and Values. Changes in students' attitudes toward sustainability were evident in how they described responsibility and the role of engineers. Post-camp responses more frequently expressed a sense of personal and professional responsibility for considering sustainability in engineering decisions. Students described sustainability as something engineers "should consider" or "are responsible for," rather than as an optional or external concern.

Several responses also reflected increased awareness of social and community dimensions of sustainability. Students discussed the importance of designing solutions that benefit communities and avoid negative social consequences. While not all students explicitly referenced equity or justice, post-camp responses demonstrated greater sensitivity to the human impacts of engineering work.

Sustainability-Related Behaviors and Intentions. Students' post-camp responses included more explicit references to intended actions related to sustainability. These included intentions to apply sustainability principles in future coursework, to consider sustainability when making engineering decisions, and to adopt more sustainable practices in personal contexts.

Rather than describing specific behaviors already enacted, students most often articulated anticipated behaviors and commitments. These expressions suggest that the immersive experience influenced how students envisioned incorporating sustainability into their academic and professional trajectories. Such intentions are interpreted as early indicators of sustainability mindset development rather than as evidence of behavioral change.

Cross-Cohort Observations. Although this study was not designed to compare outcomes across cohorts, qualitative differences were observed in how students articulated their learning following the two camp formats. Students who participated in the applied, design-centered camp more frequently described action-oriented thinking and referenced implementation considerations. Students from the reflection-focused camp more often emphasized conceptual understanding and awareness.

These observations are presented to illustrate how variations in immersive learning design may shape the ways students express sustainability-related learning. They are not intended to imply differential effectiveness or causal relationships.

Summary of Findings. Taken together, the results indicate that participation in the immersive

summer camp was associated with qualitative shifts in how first-year engineering students described sustainability-related knowledge, skills, attitudes, and behaviors. Students' post-camp responses reflected more integrated sustainability conceptions, greater emphasis on responsibility, and increased articulation of intended future actions. These findings provide descriptive insight into sustainability mindset development in an early, immersive educational context and inform the discussion of program design and implications presented in the following section.

Discussion

This study examined how first-year engineering students articulated sustainability-related learning following participation in an immersive Sustainability Engineering summer camp. The findings provide descriptive insight into how early, short-duration experiential learning environments may support sustainability mindset development across knowledge, skills, attitudes, and intended behaviors. Rather than demonstrating effectiveness or causal impact, the results illuminate how students framed sustainability and professional responsibility after engaging in a concentrated, sustainability-focused experience.

Early Sustainability Exposure and Mindset Development. One of the most salient findings of this study is the shift in how students described sustainability following the immersive experience. Post-camp responses reflected broader, more integrated conceptions of sustainability that extended beyond environmental considerations to include social, economic, and community dimensions. This shift aligns with prior work that frames sustainability as a multidimensional competency rather than a discrete technical topic [2, 7].

The early timing of the intervention is particularly noteworthy. Introducing sustainability concepts before students begin their first semester of engineering coursework may influence how they interpret subsequent learning experiences and professional expectations. Prior research on engineering identity development suggests that early experiences play a formative role in shaping students' perceptions of what it means to be an engineer [8, 19]. In this context, the immersive summer camp may have served as an entry point for integrating sustainability into students' emerging engineering identities, rather than positioning it as an add-on encountered later in the curriculum.

Role of Immersive and Applied Learning Experiences. The findings also highlight the role of immersive and experiential learning environments in shaping how students articulate sustainability-related skills and intentions. Students' post-camp responses emphasized collaboration, problem-solving, and consideration of constraints and tradeoffs—elements commonly associated with authentic engineering practice. These observations are consistent with experiential learning theory, which emphasizes learning through engagement, reflection, and application [9, 10].

Qualitative differences observed between the reflection-focused and applied, design-centered camp formats further suggest that learning design influences how students express sustainability-related learning. Students who participated in applied activities more frequently articulated action-oriented thinking and implementation considerations, while those in reflection-focused activities emphasized awareness and conceptual understanding. These patterns align with prior research suggesting that

design-centered and situated learning environments encourage students to grapple with real-world constraints and decision-making processes [11, 16]. Importantly, these observations are interpreted as differences in expression rather than evidence of differential effectiveness.

Sustainability, Responsibility, and Justice-Oriented Perspectives. Another important finding relates to students' articulation of responsibility and the role of engineers in addressing sustainability challenges. Post-camp responses more frequently framed sustainability as an expected component of engineering practice rather than as an optional concern. Several students also demonstrated increased awareness of the human and community impacts of engineering decisions.

These findings resonate with recent scholarship that connects sustainability mindset development with principles of diversity, equity, inclusion, and justice. Santiago-Román et al. emphasize that sustainability engineering education should explicitly engage students with social context and equity considerations as part of responsible engineering practice [12]. Similarly, Colón-Rivera et al. show that sustainability-focused learning experiences can serve as a pathway for introducing DEIJ principles in early engineering education [14]. While this study did not explicitly assess students' adoption of DEIJ frameworks, the increased attention to community impact and responsibility observed in post-camp responses suggests that immersive sustainability experiences may create space for such perspectives to emerge.

Implications for Assessment and Program Design. The findings also have implications for how sustainability learning is assessed in early and immersive contexts. Students' responses primarily reflected changes in framing, awareness, and intended behaviors rather than measurable performance gains. This pattern is consistent with prior work noting that sustainability mindset development involves gradual shifts in values and perspectives that may not be readily captured through traditional assessment instruments [17].

The use of qualitative, open-ended surveys allowed students to articulate their understanding of sustainability in their own words, providing insight into how they connected sustainability concepts to personal and professional contexts. This approach aligns with recommendations for qualitative methods in exploratory engineering education research, particularly when examining complex, value-laden constructs such as sustainability mindset [18].

From a program design perspective, the results suggest that immersive summer camps can serve as meaningful entry points for sustainability education when intentionally structured. Design choices—such as emphasizing applied problem solving or reflective discussion—appear to influence how students express sustainability learning. These insights may inform the design of future sustainability-focused immersive experiences, as well as the integration of sustainability across curricular and co-curricular pathways.

Limitations and Interpretation. As an exploratory study conducted within a specific institutional context, this work has several limitations. Findings are based on a small number of participants and short-term qualitative data, and they are not intended to be generalized broadly. Additionally, differences observed between camp formats should be interpreted cautiously, as the study was not designed to compare outcomes or establish causal relationships.

Despite these limitations, the study contributes descriptive insight into how first-year engineering students articulate sustainability learning following an immersive experience. These insights provide a foundation for future research that may examine longer-term outcomes, incorporate additional data sources, or explore sustainability mindset development across multiple educational contexts.

Contribution to Engineering Education Research. This study contributes to engineering education research in three important and complementary ways. First, it provides empirical, design-informed evidence that sustainability mindset development can begin meaningfully before students enter formal engineering coursework. While much prior research has examined sustainability learning in upper-division courses or capstone experiences, this study demonstrates that first-year, pre-matriculation immersive interventions can influence how students conceptualize sustainability, professional responsibility, and the role of engineers in society. By focusing on an early intervention, the study expands current understanding of when and how sustainability-oriented ways of thinking can be introduced within engineering pathways.

Second, the study advances understanding of how immersive learning design shapes the expression of sustainability-related learning. By examining two camp formats implemented in consecutive years, the findings illustrate how applied, design-centered activities may encourage more action-oriented sustainability thinking, whereas reflection-focused structures may emphasize conceptual awareness and perspective shifts. These observations contribute to emerging design knowledge for sustainability-focused experiential programs and offer transferable insights for educators making intentional design choices in short-duration, immersive contexts.

Third, this work demonstrates the value of qualitative, bilingual assessment approaches for examining early-stage sustainability mindset development. The use of open-ended prompts in both English and Spanish supported inclusive participation and enabled students to articulate nuanced shifts in sustainability-related knowledge, attitudes, and intentions that may not be captured through traditional assessment instruments. This approach underscores the importance of methodological alignment when studying complex, value-laden constructs such as sustainability mindset.

Taken together, these contributions position immersive summer programs not only as outreach or recruitment mechanisms, but as legitimate and productive sites of engineering education research and innovation in sustainability education.

Conclusions and Implications

This study explored how first-year engineering students articulated sustainability-related learning following participation in an immersive Sustainability Engineering summer camp at the University of Puerto Rico, Mayagüez. Using qualitative analysis of pre- and post-camp open-ended survey responses, the study provides descriptive insight into how students' understandings of sustainability, perceptions of professional responsibility, and anticipated behaviors evolved over the course of a short-duration immersive experience.

Overall, the findings suggest that immersive early interventions may support sustainability mindset development by broadening how students conceptualize sustainability and by encouraging consideration of social, environmental, and community impacts as integral components of engineering practice. Students' post-camp responses reflected more integrated sustainability framings, increased articulation of responsibility, and greater emphasis on future application of sustainability principles. These shifts were observed across knowledge, skills, attitudes, and intended behaviors, highlighting the value of holistic analytic lenses for examining sustainability learning.

Differences in how students articulated their learning across the two camp formats further underscore the role of learning design in shaping sustainability-related outcomes. While the study was not designed to compare effectiveness, the findings suggest that applied, design-centered activities may prompt more action-oriented expressions of sustainability learning, whereas reflection-focused activities may emphasize conceptual awareness. These observations reinforce the importance of intentional pedagogical choices when designing immersive sustainability experiences.

From an educational practice perspective, the results have several implications. First, immersive summer camps can serve as meaningful entry points for sustainability education at the beginning of students' engineering pathways. Introducing sustainability before formal coursework begins may influence how students frame subsequent learning experiences and professional expectations. Second, integrating applied problem-solving activities alongside opportunities for reflection may support more comprehensive sustainability mindset development by engaging both conceptual understanding and action-oriented thinking. Third, qualitative assessment approaches are well suited for capturing early-stage sustainability learning, particularly when outcomes involve shifts in perspective, values, and intentions rather than immediate performance gains.

This study also has implications for future research. Given the exploratory nature of the work and the short duration of the intervention, additional research is needed to examine the persistence of sustainability mindset development over time and across curricular contexts. Longitudinal studies, integration of multiple data sources, and examination of sustainability learning in later stages of the engineering curriculum would provide further insight into how early immersive experiences influence students' professional development.

In conclusion, this study contributes to the growing body of engineering education research that positions sustainability as a foundational element of professional formation rather than a peripheral topic. By providing design-informed, qualitative evidence from an early immersive intervention, this work extends existing scholarship by demonstrating how sustainability mindset development can begin prior to formal engineering coursework. The study offers both empirical insight and practical, design-relevant guidance for educators seeking to integrate sustainability meaningfully at the start of the engineering curriculum.

The findings suggest that when immersive experiences are intentionally structured to balance reflection and applied problem solving, they can shape how first-year students frame sustainability, responsibility, and action as integral dimensions of engineering practice rather than as isolated concerns. As engineering programs continue to respond to global sustainability challenges, early, immersive learning environments represent a promising—and still underexplored—lever for fos-

tering sustainability-oriented ways of thinking that can be reinforced and deepened throughout students' academic pathways.

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