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Sustainability Engagement and Career Aspirations Among Underrepresented Engineering Students: Insights from a Comparative Analysis

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ABSTRACT: Integrating sustainability into engineering education is critical for addressing climate change and its impacts on communities disproportionately affected by environmental challenges. Yet, little research has examined how underrepresented minority (URM) students at minority-serving institutions (MSI) perceive and engage with sustainability-related content and careers. Accordingly, this study investigates the relationships among demographics, sustainability engagement, and career aspirations in 124 undergraduate engineering students at a MSI – Hispanic-serving institution – surveyed from January to February 2024. Survey items were measured on a five-point Likert scale with strong internal consistency (Cronbach's $\alpha = .833$). Non-parametric analyses including the Mann-Whitney U test and Kruskal-Wallis test revealed that URM students reported higher confidence in sustainable engineering solutions and stronger preferences for sustainability content compared to non-URM peers, highlighting a strengths-based perspective that emphasizes URM students' potential leadership in sustainability. Gender significantly influenced sustainability interest and regional needs perception with female students expressing greater interest in sustainability. Additionally, students' academic year in their university program significantly affected both sustainability engagement and career aspirations. These findings are especially relevant for civil and architectural engineering students, who play a vital role in shaping sustainable practices in design, construction, and operation and the built environment. Overall, this research highlights the strengths and unique perspectives that historically marginalized students bring to engineering education, particularly in sustainability contexts. This has important implications for engineering education policy and curriculum design, particularly in developing more inclusive and effective sustainability education programs that leverage diverse student experiences.

1. INTRODUCTION

The integration of sustainability into engineering education is increasingly critical in addressing the multifaceted challenges posed by climate change, resource depletion, and social inequities. Traditional engineering education has historically focused on technical proficiency and cost-efficiency, often overlooking the broader environmental and societal impacts of engineering solutions (Tisdale & Bielefeldt 2024). This gap is particularly concerning in civil and architectural engineering, where building construction and operations account for nearly 40% of global carbon emissions (Ahmed et al. 2022), demanding innovative approaches that balance economic, environmental, and social dimensions. Sustainability in engineering emphasizes the development of solutions that are not only technically sound but also environmentally responsible and socially equitable (Sagaris et al. 2024). The civil and architectural engineering sector faces specialized challenges in achieving decarbonization targets, particularly in developing, for example, sustainable construction materials and energy-efficient building systems. However, existing engineering curricula often lack comprehensive integration of sustainability principles, which could leave graduates less equipped to address these pressing global and equity-focused challenges (Hąbek et al. 2024). In addition, in the case of infrastructure engineering, de-contextualized approaches has been commonly applied (Sanford et al. 2022). As industries and societies worldwide increasingly adopt sustainability-focused frameworks, such as the United Nations Sustainable Development Goals (SDGs), incorporating these principles into engineering education is essential for preparing future engineers to navigate and address these complex challenges effectively.

Existing literature on sustainability engagement in engineering education explored various dimensions, including the integration of sustainability principles into engineering curricula, student attitudes toward sustainability, and the influence of sustainability education on career aspirations. For instance, Burke et al. (2018) and Bielefeldt (2011) highlighted the potential of sustainability content to broaden participation in engineering and examined instructors' perspectives on integrating sustainability into civil and architectural engineering courses. Similarly, research by Ken-Giami et al. (2022) and Verdín et al. (2018) shed light on the career outcome expectations of specific groups, such as women engineers and community college students, respectively. While these studies provided valuable insights, much of the research focused on either women, first-year students, or faculty/instructors, often overlooking the comprehensive perspectives of underrepresented minority (URM) students in engineering, such as female, Black/African, Hispanic/Latinx, Indigenous, low-income, or first-generation populations. This knowledge gap is particularly significant as URM students often come from communities disproportionately impacted by environmental challenges and climate change (United States Environmental Protection Agency 2021) . Furthermore, there remained a limited understanding of how demographic factors and socioeconomic status influence student engagement with sustainability-related education and career opportunities, particularly within minority-serving institutions (MSIs). MSIs represent a diverse group of higher education institutions that historically served as critical points of entry to college for traditionally underrepresented students (Gasman et al. 2015). These institutions include the following:

- **Hispanic-Serving Institutions (HSIs):** A postsecondary institution that enrolls 25% or more Latinx students (Garcia & Dwyer 2018),
- **Historically Black Colleges and Universities (HBCUs):** Institutions of higher education established before 1964 with the primary purpose of educating Black Americans (Allen et al. 2007),
- **Tribal Colleges and Universities (TCUs):** Higher education institutions that support for revitalization of culture and identity and individual and tribal self-determination (Crazy Bull et al. 2020),
- **Asian American, Native American, and Pacific Islander Serving Institutions (AANAPISIs):** These are institutions recognized under the Higher Education Act that enroll at least 10% of undergraduate students who identify as Asian American, Native American, or Pacific Islander (Nguyen et al. 2020).

These institutions were established in response to the educational needs of their respective communities, playing a vital role in expanding access to higher education for students from diverse racial, ethnic, and socioeconomic backgrounds.

Addressing these limitations, our research examines sustainability engagement patterns and career aspirations among undergraduate engineering students, including civil and architectural engineering, with a specific emphasis on underrepresented groups, to inform the development of more inclusive and impactful sustainability education strategies. Given these considerations, this research addresses the following research questions (RQs):

- **RQ1:** What are the sustainability engagement patterns (i.e., behaviors, attitudes, and perceptions) and career aspirations among undergraduate engineering students?

- **RQ2:** How do sustainability engagement patterns and career aspirations vary among different student groups, particularly between underrepresented and overrepresented students, and across gender, race/ethnicity, year in university, and scholarships or grants eligibility?

To address these research questions, we conducted a survey-based study involving undergraduate engineering students at an HSI. The survey captured data across several key dimensions: demographic characteristics, sustainability engagement patterns, and career aspirations. These data were analyzed using Mann-Whitney U tests, and Kruskal-Wallis tests, to examine differences in perceptions and engagement across survey subgroups. The findings provide a foundation for understanding how underrepresented and overrepresented groups engage with sustainability in engineering education and inform strategies for more inclusive and impactful educational practices.

2. LITERATURE REVIEW

A growing body of research highlights the multifaceted impact of sustainability education on student engagement, career aspirations, and societal outcomes. Sperling et al. (2024) demonstrated that early exposure to sustainability concepts and principles through a first-year undergraduate engineering design course significantly improved students' self-efficacy and professional skills development. Expanding on this educational impact, Nogueira et al. (2023) examined sustainability education in Portuguese engineering schools, revealing that sustainability-focused coursework not only strengthened students' beliefs and attitudes but also enhanced their future intentions toward sustainability implementation, particularly among students with higher emotional intelligence. In the context of minority-serving institutions, Muldrow et al. (2019) emphasized the importance of interdisciplinary sustainability education for underrepresented minority students, highlighting the role of faculty engagement in curriculum development. Within civil engineering programs, Miller and Brumbelow (2017) discovered that incoming students exhibited favorable attitudes toward sustainability principles, regardless of whether these concepts were explicitly presented or embedded within related topics such as natural resource conservation. In examining the relationship between sustainability and career choices, Klotz et al. (2014) revealed that students' desire to address sustainability challenges such as energy issues, climate change, environmental degradation, and water supply significantly increased their likelihood of pursuing engineering careers. The intersection of sustainability education with demographic factors has emerged as a crucial area of study. Analyzing data from ninth-grade students, Mau and Li (2018) found that race, gender, and socioeconomic status, along with math interest and science self-efficacy, were the most significant predictors of STEM career aspirations.

While existing literature demonstrates the importance of sustainability education in fostering environmental awareness and career readiness, it often overlooks variations in engagement patterns across different demographic groups. This limitation particularly affects our understanding of how factors such as gender, race/ethnicity, and socioeconomic background influence students' interactions with sustainability concepts. Our current study addresses this by adopting an inclusive and comparative approach, aiming to develop tailored educational strategies that effectively support underrepresented engineering students in pursuing sustainability-focused careers.

3. RESEARCH METHODOLOGY

3.1 Survey Development and Distribution

This study employed a quantitative, cross-sectional survey design to investigate sustainability perceptions, engagement patterns, and career aspirations among undergraduate engineering students, with a specific focus on URM groups.

Data collection was carried out using an online questionnaire hosted on the Qualtrics platform supported by the University of Arizona (U of A). The online approach allowed efficient collection of data from a large student population. The survey instrument was distributed through the College of Engineering listserv email containing detailed information about the study's purpose and significance. Participants were incentivized with the opportunity to enter a random drawing for a gift card, while strict confidentiality and anonymity protocols were maintained.

This cross-sectional survey was developed to capture a holistic view of how students' demographic backgrounds relate to their engagement with sustainability, academic content preferences, and career aspirations. The survey comprised 24 items organized into two main sections:

- **Demographic information (7 items):** We collected data on students' demographic information, such as gender, engineering major, and familiarity with sustainability.
- **Students' engagement with sustainability, academic content preferences, and career aspirations (17 items):** The second section of the survey instrument measured students' sustainability engagement, academic content preferences, and career aspirations using a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree).

Prior to full deployment, we conducted preliminary testing of the survey with five undergraduate engineering students. During this pilot phase, students completed the survey and provided feedback on question wording, comprehension, and relevance. Based on their feedback, modifications were made to improve clarity, such as simplifying technical terminology and providing specific examples where needed. This iterative refinement process helped ensure that the final survey questions were clear and understandable to the target student population.

We gathered responses between January and February 2024 after getting an approval from U of A Institutional Review Board.

3.2 Survey Participants

The survey garnered 189 initial responses during its one-month collection period, with 124 responses (65.1% completion rate) meeting the completeness criteria for analysis. Excluded responses included surveys with substantial missing data, and incomplete demographic information. Initial reliability analysis demonstrated strong internal consistency for the overall instrument ($\alpha = 0.833$). This indicates reliable measurement of students' sustainability-related perceptions and aspirations.

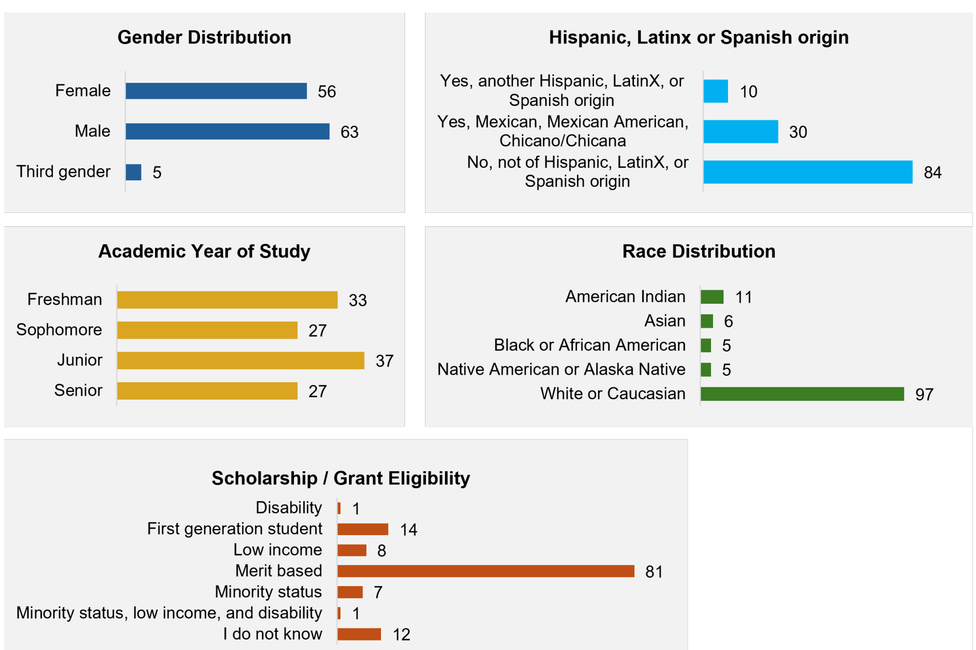

Figure 1: Demographic data of respondents

Figure 2 presents the breakdown of students categorized by academic year across various engineering majors. When considering Civil and Architectural Engineering together, they represented one of the largest groups with 21 students (Civil: n = 10; Architectural: n = 11) distributed across all academic years. Within this combined construction-focused group, juniors formed the largest cohort (n = 8), followed by freshmen (n = 5), seniors (n = 4), and sophomores (n = 4). This representation was comparable to Mining Engineering (n = 20) and exceeded Mechanical Engineering (n = 16), highlighting the strong presence of construction-related disciplines in the study.

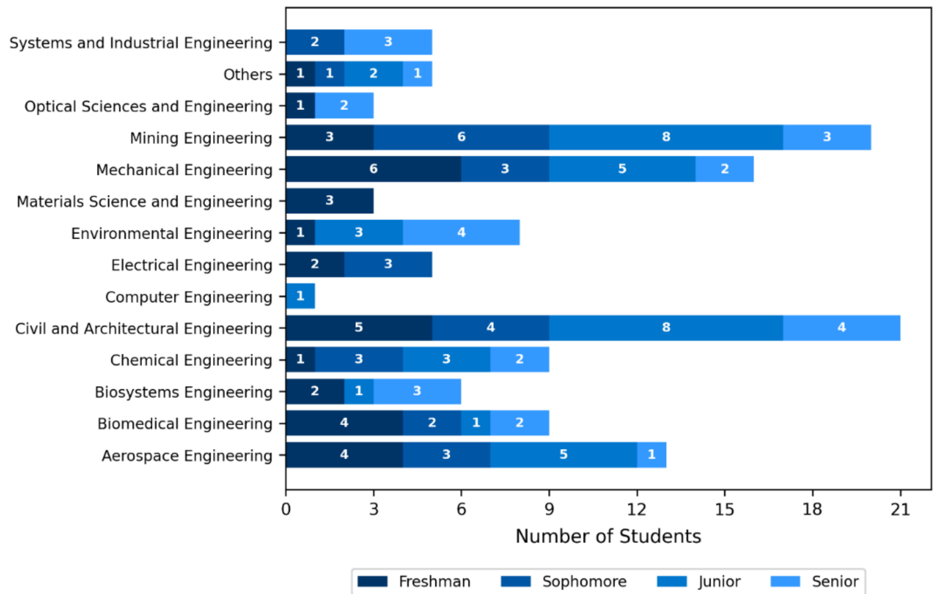

Figure 2: Engineering majors distribution by academic years

3.3 Data Analysis Method

To analyze the collected data, we first classified students as URM based on three criteria: (1) Gender identity (female and third gender); (2) Race and ethnicity (American Indian or Alaska Native; Black or African American; Hispanic, Latinx, or Spanish Origin); and (3) Scholarships or Grants eligibility (First-generation student, Low income, Minority status, Disability). Students meeting any of these criteria were categorized as URM, while those not meeting any criteria were classified as non-URM.

The distribution of the data was assessed using the Shapiro-Wilk test to determine its conformity to a normal distribution. Based on the results of this assessment showing non-normal distributions (p value < .05), non-parametric statistical methods (i.e., Mann-Whitney U tests, Kruskal-Wallis tests) were selected, as they are more appropriate for non-normally distributed ordinal data.

- **The Mann-Whitney U test:** To compare URM and non-URM students on sustainability perceptions and career aspirations. This test produces a U-statistic representing the difference between the two groups' rankings, where smaller U values indicate greater differences between groups (Nachar 2008). Statistical significance was determined using the p-value, where p value < .05 indicates a significant difference between groups.
- **Kruskal-Wallis tests:** To unravel the differences between subgroups, such as gender (male, female, non-binary/third gender), race/ethnicity, scholarship or grant eligibility (e.g., merit-based, first-generation status, low-income), and year of study regarding their sustainability engagement and career aspirations. The test produces an H-statistic that indicates the variance of ranks between groups, with larger H values suggesting greater differences between groups (Ostertagova et al. 2014). Statistical significance was determined using the p-value, where p < .05 indicates significant differences exist between at least two groups.

Also, the reliability of the survey instrument was assessed using Cronbach's alpha, with values above 0.700 considered acceptable (Tavakol & Dennick 2011).

All statistical analyses were conducted using Python (version 3.12.4), with key libraries including pandas for data manipulation, and scipy.stats for statistical testing.

4. RESULTS

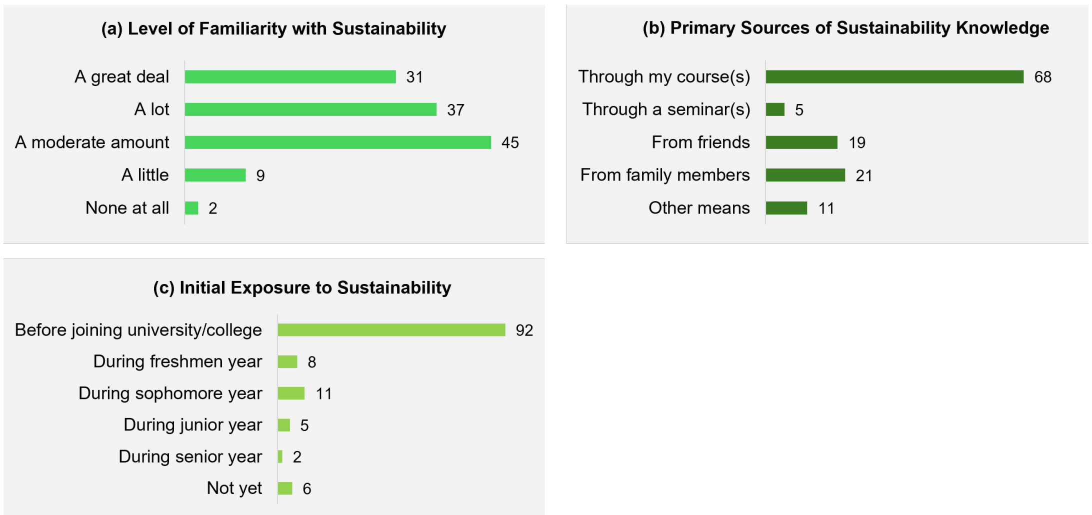

Figure 3: Familiarity with the concept of sustainability

The analysis of student responses regarding their familiarity with sustainability concepts, as presented in Figure3, revealed notable differences in the extent and timing of their exposure to sustainability topics, as well as the sources from which they gained this knowledge. A substantial majority of respondents (91.13%) indicated at least a moderate level of familiarity with the concept of sustainability. However, 8.87% reported "a little" familiarity, and 1.61% expressed no familiarity at all. The timing of students' initial exposure to sustainability further highlights disparities. A significant proportion of students (74.19%) reported learning about sustainability prior to entering university or college. In contrast, only a small subset (20.97%) began learning about sustainability during their university years. Notably, 4.84% of respondents indicated they had not yet learned about sustainability, suggesting potential gaps in curricular or extracurricular opportunities for engaging with these topics. When examining the sources of sustainability knowledge, more than half of the students (54.84%) reported learning through their university courses, emphasizing the critical role of formal education in fostering sustainability awareness. Family members (16.94%) and friends (15.32%) were also significant sources. Interestingly, 8.87% reported "other means", while seminars accounted for the smallest proportion (4.03%), indicating that structured, event-based learning plays a limited role in initial exposure to sustainability.

The results from the Mann-Whitney U test in Table 1 highlighted both similarities and differences across various dimensions of sustainability-related perceptions and behaviors. URM and non-URM groups exhibited no significant differences in their interest in sustainability, with both groups reporting similarly high mean scores (4.45 for URM and 4.39 for non-URM, p = 0.60). This indicates a shared interest in sustainability as a concept, regardless of demographic background. Similarly, when examining participation in seminars related to sustainability, no significant differences were observed (p = 0.64), with both groups showing low average engagement (mean = 2.05).

Significant differences emerged in perceptions of sustainable engineering solutions as viable alternatives to conventional practices (p = 0.04). Underrepresented minority students reported higher confidence in the feasibility of such solutions (mean = 4.22) compared to their non-URM counterparts (mean = 3.95).

Conversely, no significant differences were noted in optimism about the feasibility of sustainable engineering solutions resolving real-world problems (*p* = 0.91), with both groups expressing moderate optimism (mean = 3.92). Similarly, perceptions of familiarity with local sustainability issues showed no significant differences (*p* = 0.45).

Table 1: Mann-Whitney U Test between URM and Non-URM Groups

Survey Item	U Statistic	p-value	Mean (URM)	Mean (Non-URM)	Standard Deviation (URM)	Standard Deviation (Non-URM)
I am interested in sustainability	2010	0.60	4.45	4.39	0.77	0.83
I frequently participate in seminars by practitioners or professors related to sustainability	1829.5	0.64	2.05	2.05	1.16	0.94
I am confident that sustainable engineering solutions exist as viable alternatives to conventional engineering solutions	2296.5	0.04*	4.22	3.95	0.82	0.82
I am optimistic about sustainable engineering solutions being feasible and resolving real-world problems	1940	0.91	3.92	3.92	1.12	1.09
I am familiar with local sustainability issues	2061.5	0.45	3.52	3.44	1.09	0.97
Southern Arizona needs sustainable solutions to address its challenges	2185	0.10	4.65	4.42	0.72	0.88
I actively engage with sustainability in engineering through courses, student clubs, competitions, university organizations, or faculty interactions	2000.5	0.67	3.34	3.25	1.28	1.23
My academic program should include more sustainability-related content	2348.5	0.02*	4.14	3.71	0.7	1.03
I would be more interested in my major if it included more sustainability-related content	2440.5	0.01*	3.8	3.22	1.09	1.23
I have engaged in sustainability-related student competitions over the past year	1770	0.35	1.48	1.63	0.95	1.05
I reach out to faculty to ask how I can be involved in sustainability-related projects, research, or activities	1824.5	0.60	1.69	1.83	1.03	1.19
I have conducted research related to sustainability.	1891	0.88	1.85	1.81	1.31	1.2
I am interested in pursuing a job that incorporates sustainable engineering practices	2040.5	0.51	4.32	4.24	0.79	0.8
I would be interested in a job that incorporates sustainable engineering practices	2024	0.56	4.38	4.27	0.78	0.93
I frequently see job positions emphasizing their associations with sustainability	2053	0.48	3.42	3.24	1.04	1.18
Sustainability is one of my priorities when selecting my career	1882.5	0.86	3.57	3.59	1.13	1.13
Commitment to sustainability is a professional's responsibility	1833.5	0.64	4.34	4.34	0.73	0.9

* Statistically significant ($p < 0.05$); Rows highlighted in light yellow indicate items where significant differences were found between URM and non-URM groups.

Additionally, significant differences were identified regarding the perception of sustainability-related content in academic programs. Underrepresented minority students more strongly believed that their academic programs should include additional sustainability-related content (*p* = 0.02), with a higher mean score (4.14) compared to non-URM students (mean = 3.71). Furthermore, URM students showed stronger preference for sustainability integration in their major (*p* = 0.01, mean = 3.8 vs. 3.22 for non-URM). Both groups expressed high interest in pursuing careers that incorporate sustainable engineering practices, with no significant differences observed (*p* = 0.51, mean = 4.32 for URM and 4.24 for non-URM). Similar trends were observed for general interest in jobs incorporating sustainable practices (*p* = 0.56, mean = 4.38 for

URM and 4.27 for non-URM). Likewise, perceptions of sustainability as a priority in career selection and as a professional responsibility showed no significant differences, with both groups demonstrating strong alignment on these aspects (p = 0.86 and p = 0.64, respectively).

Table 2: Kruskal-Wallis Test

Variable	**Subgroup**	H-Statistic	P-value
I am interested in sustainability	Gender	6.34	0.04*
Southern Arizona needs sustainable solutions to address its challenges	Gender	7.00	0.03*
I actively engage with sustainability in engineering through courses, student clubs, competitions, university organizations, or faculty interactions	Year in University	10.25	0.02*
I would be more interested in my major if it included more sustainability-related content	Gender	12.36	0.00*
I reach out to faculty to ask how I can be involved in sustainability-related projects, research, or activities	Year in University	9.11	0.03*
I am interested in pursuing a job that incorporates sustainable engineering practices	Year in University	10.67	0.01*
I would be interested in a job that incorporates sustainable engineering practices	Gender	7.02	0.03*
	Year in University	8.43	0.04*
I frequently see job positions emphasizing their associations with sustainability	Year in University	12.84	0.00*

Note: Only items showing statistically significant differences ($p < 0.05$) are presented in this table.

The Kruskal-Wallis test results, presented in Table 2, provide insights into how various demographic factors influence sustainability-related perceptions and career aspirations among engineering students. Gender differences were evident in students' interest in sustainability (H = 6.34, p = 0.04) and their belief that Southern Arizona needs sustainable solutions to address its challenges (H = 7.00, p = 0.03). Furthermore, preferences for incorporating sustainability-related content in academic programs showed significant gender differences (H = 12.36, p < 0.001). Although no statistically significant differences were detected across race/ethnicity for most variables, certain trends emerged that warrant further exploration. For example, familiarity with local sustainability issues and optimism about sustainable engineering solutions showed higher variability among racial and ethnic subgroups, with minority groups often expressing greater concerns and aspirations related to sustainability. However, these differences did not reach statistical significance (H = 18.86, p = 0.09 and H = 16.31, p= 0.18, respectively). Significant differences were identified in students' sustainability engagement based on their academic year in the university program. For example, active engagement with sustainability through courses, clubs, or competitions showed significant variation across academic levels (H = 10.25, p = 0.02), with juniors and seniors demonstrating higher levels of participation. Similarly, interest in pursuing sustainability-focused careers (H =10.67, p = 0.01) and engagement with job descriptions emphasizing sustainability (H = 12.84, p < 0.001) were higher among juniors and seniors.

While gender emerged as a significant factor influencing sustainability interest and curriculum preferences, race/ethnicity and scholarship status did not reveal substantial differences in most sustainability dimensions. Academic year in the university program, however, consistently influenced both engagement levels and career aspirations.

5. CONCLUSION

This study contributes to the understanding of how undergraduate engineering students at a MSI perceive and engage with sustainability-related content and career opportunities. By focusing on demographic factors such as gender, race/ethnicity, year of study, and scholarship status, the research highlights differences in sustainability engagement and career aspirations between URM and non-URM students.

The findings provide valuable insights into patterns of engagement and perception across diverse student groups, leveraging non-parametric statistical analyses such as the Mann-Whitney U test and Kruskal-Wallis test. Results revealed that URM students exhibit greater confidence in the viability of sustainable engineering solutions and express a stronger preference for integrating sustainability-focused content into their academic programs. Gender differences were also significant, with female students demonstrating a heightened sense of urgency for addressing sustainability challenges. Additionally, students in their junior and senior years were more likely to engage actively with sustainability-related opportunities and express aspirations for careers centered on sustainable practices, emphasizing the role of academic exposure in shaping sustainability engagement.

This study makes important contributions to the intersection of sustainability education and diversity in STEM by identifying specific areas for enhancing inclusion in engineering programs. We recommend the following approaches for more inclusive sustainability education: (1) Gender-responsive curriculum elements. Specifically, for male students, course modifications that connect sustainability to technical problem-solving challenges and competitive design elements may better align with their learning preferences; (2) Progressive engagement strategies that introduce sustainability concepts early for first and second-year students while offering more advanced applications for juniors and seniors. This will address the observed differences in engagement across academic years; and (3) Culturally responsive teaching approaches that connect sustainability challenges to communities historically affected by environmental inequities, building on URM students' demonstrated confidence in sustainable engineering solutions. These targeted educational strategies can be implemented through project-based learning, mentorship programs featuring diverse role models, and community-based learning opportunities that emphasize the relevance of sustainability to diverse populations.

While this study offers important insights, some limitations need be acknowledged. First, the data collection was limited to a single MSI, which may not fully represent the experiences of engineering students at other institutions. Second, the cross-sectional nature of the study prevents us from tracking how individual students' sustainability engagement evolves throughout their academic journey. Third, while our quantitative approach provided valuable statistical insights, it limited our ability to capture the complete perspectives and lived experiences of students that could explain the observed patterns. Future research should address these limitations by: 1) Expanding to both MSIs and non-MSIs, to enable broader comparisons; 2) Conducting longitudinal studies to track changes in student engagement and career aspirations over time; and 3) Employing mixed-methods approaches, including interviews or focus groups, for a more holistic view of students' sustainability attitudes and behaviors that would yield a richer understanding of the underlying factors influencing their engagement with sustainability.

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