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High School Students' Perspectives on Pre-college Engineering Education Courses (Fundamental)

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Abstract

Since the introduction of Next Generation Science Standards (NGSS) in 2013, pre-college engineering education has been on the rise. However, the impact of pre-college engineering education courses on high school students' perceptions of future careers remains unclear. Engineering for US All (e4usa) aims to establish an accessible engineering education environment by offering introductory engineering courses to high school students. The core objective is to enhance high school students' understanding of the engineering design process and the real-world roles of engineers, empowering them to make well-informed career choices. This paper focuses on examining the aspects of the pre-college engineering education curriculum that are appreciated by the students which may influence engineering as their future career choice.

The study is part of a larger research project, where the research team conducted surveys of students participating in the e4usa during the 2022-2023 academic year. The survey was administered in 33 schools across 20 states and regions in the U.S. A qualitative analysis was conducted on the open-ended responses from the pre-test (n= 623) and post-test (n= 296) surveys. We analyzed students' perspectives on 1) their preferred and least favored aspects of the engineering course and 2) their anticipated professions. We also conducted a quantitative analysis on the connections between student demographic data and their consideration of future engineering careers.

Results discuss five emergent themes impacting students' engagement in pre-college engineering courses: Projects, Engineering Design Process, Flexibility and Creativity, Assignment and Writing, Timeframe. We also noted a significant increase in students' interest in engineering in the post-test, especially for female students. Strengthening pre-college engineering education to assist students in pursuing higher education and careers in the field of engineering has become an urgent imperative. This paper will contribute to the growing body of knowledge on how Generation Z perceives engineering and provide insights for the enhancement of future engineering education programs.

Introduction

In 2013, the National Research Council (NRC) introduced the Next Generation Science Standards (NGSS), emphasizing the integration of science, technology, engineering, and mathematics (STEM). These standards highlight engineering and aim to prepare K-12 students for education and careers in the 21st century [1]. According to projections by the United States Department of Labor, there is expected to be a 10.8% growth in STEM jobs from 2022 to 2032, significantly outpacing the anticipated 2.3% growth in non-STEM occupations [2].

Research shows that encouraging high school students to participate in engineering courses increases their interest in pursuing engineering careers. For example, A two-week simulated design engineering camp for high schoolers found a significant transformation in participants' perceptions of engineering and technology, particularly in inspiring female students to contemplate a career in engineering [3]. Another study with a three-year intervention with female high school sophomores found that young women are capable of cultivating a substantial interest in engineering during their high school years [4]. However, a longitudinal study revealed a notable drop in STEM career intentions between 9th and 11th grade [5].

Engineering for US All (e4usa), launched in 2018 with National Science Foundation funding, aims to make engineering education more accessible in high schools. It introduces an innovative curriculum that focuses on engineering literacy and essential professional skills through practical design experiences. The e4usa objectives include introducing the engineering design process to all students, fostering interdisciplinary thinking and collaboration, providing a pathway to engineering majors, and promoting inclusivity [6].

As part of the larger e4usa initiative, this study aimed to investigate high school students' perspectives on engineering education courses and their impact on career choices. We investigated two primary questions: 1) What characteristics of high school engineering courses contribute to fostering an environment that engages students in learning? 2) How does exposure to an engineering course affect high school students' interest in pursuing engineering careers?

Literature Review

Pre-college engineering education has seen significant growth in the last decade and related research shows that pre-college engineering education is crucial for the transition to university-level engineering study. Salzman, Ricco, and Ohland [7] indicated that 89 percent of domestic students entering first-year engineering courses at universities had pre-college engineering experiences. These experiences were most commonly acquired through high school classes, followed by extracurricular activities, summer camps or programs, and middle school classes. Moreover, students with increased exposure to pre-college engineering and programming tended to perform better in programming-focused college courses despite lower math course grades [8].

Previous studies have also demonstrated that pre-college engineering education could enhance students' understanding of engineering concepts and contribute to students' interest and confidence in pursuing future engineering careers. According to Johnson et al., pre-college students demonstrated the capability to grasp and apply basic systems engineering principles, representing a more advanced approach to engineering design [9]. A large-scale study involving over 3000 students aged 9 to 14 observed significant improvements in students' interest, self-efficacy, stereotypes, and utility perceptions of engineering after participating in an engineering workshop [10]. Similarly, design experiences in secondary school education have been shown to develop students' practical and professional skills. The activities influenced their self-efficacy beliefs and shaped their future career interests [6].

One of the key outcomes of pre-college engineering education is the positive impact on promoting equity. For example, a one-day workshop for high school girls improved attitudes toward STEM fields, boosted their confidence in engineering, and enhanced their knowledge of career opportunities [11]. Likewise, a one-year Engineering Projects in Community Service program for high school students enhanced students' perceptions of engineers, social responsibility, resilience, and innovation. The program also revealed improved knowledge of engineering and refined career goals, with notable benefits observed among female and Asian students [12].

Shi [13] identified that the engineering gender gap primarily resulted from differences in secondary school participation rather than variations in postsecondary enrollment. Additionally, females were less likely to transition their interest in engineering from high school to a college major choice, a phenomenon attributed to their ability, beliefs, and preferences related to prosocial and professional factors. Moreover, there was a lack of understanding of the diverse nature of the engineering field among students, which suggested that pre-college engineering programs and curricula should continue to address a wide range of topics, aiming to attract a broader student group [14]. This study aimed to understand perspectives regarding the e4usa course and its impact on future career choices from a diverse group of high school students.

Methods

We used a survey instrument to gather data from high school students enrolled in the e4usa course in the 2022-23 academic year. The survey was developed by the e4usa research team adapting a previously tested model of Social Cognitive Career Theory (SCCT) by Lent et al. [15]. SCCT explains students' development of vocational and academic interests, and career-related choices and decisions [16]. It specifically considers how environmental variables combined with learning experiences inform career decision-making. Though the survey included items related to engineering-related self-efficacy, outcome expectations, support, and intentions; for this study, we focused on the responses to open-ended survey questions which included: 1) What did you like best about this class? 2) What did you like least about this class? 3) What do you foresee as your desired profession?

The survey was conducted with 788 students. Our research involved both qualitative and quantitative analyses of open-ended responses from the pre-test (n=623) and post-test (n=296). Due to the anonymous nature of the survey, there is no 1:1 correlation between the pre-survey responses and the post-survey responses.

The survey encompassed high school students from 33 schools across 20 states and regions, including Arizona, California, the District of Columbia, Florida, Hawaii, Illinois, Indiana, Kentucky, Maryland, Massachusetts, New Hampshire, New Jersey, New Mexico, New York, North Carolina, Pennsylvania, Rhode Island, Tennessee, the U.S. Virgin Islands, and Virginia. Table 1 displays the demographic data of the students.

Table 1. Distributions of the Demographic Data.

Category	Subcategory	Pre-test (%)	Post-test (%)
Ethnicity	White	24	27
	Black/African American	16	9
	Latino/Hispanic/Mexican American	40	13
	Asian	8	13
	Mixed	6	6
	Other	1	1
Gender	Male	53	44
	Female	36	26
	Non-binary	3	2
Grade	9th	12	21
	10th	33	25
	11th	17	20
	12th	25	20

Analysis

For the qualitative analysis, our team examined responses to two post-test survey questions: 1) What did you like best about this class? and 2) What did you like least about this class? We employed two rounds of thematic coding for each question. For the quantitative analysis, our team first cleaned data, retaining responses (n=402) provided at the beginning of the course that would qualify as the pre-test. After cleaning the data, we coded the responses to the question "What do you foresee as your desired profession?" from both pre-test and post-test surveys. According to students' responses, we classified their career interests into three categories: "Engineering", "STEM but not engineering", and "Not STEM". Additionally, student demographic data were coded. Based on the coding results and the characteristics of the student sample, we performed chi-square tests to compare students' career choices between the pre- and post-test groups.

Results

RQ1: Characteristics of engineering courses that foster an engaging learning environment

The first research question explored the characteristics of engineering courses that fostered an engaging learning environment. Table 2 highlights the frequency of the top three most and least favored aspects of the engineering courses as reported by students. Interestingly, “Projects” elicited mixed responses, featuring both the most and least favored aspects. Other best-like aspects emerged around the Engineering Design Process, and Flexibility and Creativity, while the least-liked themes included Assignment and Writing, and Timeframe.

Table 2. Top Three Best and Least liked Aspects of the Courses.

Best Liked Aspects	Count	Freq (%)	Least Liked Aspects	Count	Freq (%)
Projects	207	70	Assignment and Writing	108	36
Engineering Design Process	156	39	Projects	73	24
Flexibility and Creativity	100	25	Timeframe	22	7

Concerning Projects, students highlighted the motivational impact of hands-on activities. One student shared, “[I like] how we had hands-on work like our egg drop and building a bridge out of cardboard.” Others echoed this sentiment by mentioning the aspect of building: “ [I like] actually building things” or “I enjoyed the hands-on building parts of the course.” Teamwork was also a crucial component. Students reported that “..., and I also liked being able to work in a group because it allowed us to converse and bounce ideas off one another”, and “It was fun to create things and work with my friends.” However, a few students also voiced their dissatisfaction with the projects. For example, students mentioned, “Some of the projects were not as interesting as others (eg. pasta car vs water filter).” Others were dissatisfied with the teamwork by saying, “Having to work in teams because that meant having to wait for the rest to catch up or you would have to do their part because that grade would go even straight.”

The Engineering Design Process was another positive aspect where students recognized its real-world applications. A student remarked, “The ability to research, develop, text, and implement solutions to real-world problems given by stakeholders is simply unmatched. ... The class offers a good introduction to not just engineering in general, but what pursuing such a career has to offer.” Additionally, students valued the practical application of this process, as evidenced by comments as, “I enjoyed ... creating new pieces with 3D printers to create solutions to our problems, and re-evaluating how well these pieces work and remaking them if necessary until they work as we want them too.”

Flexibility and Creativity were also noted as significant elements of the course. One student expressed, “I like the amount of freedom I am given, either I get to choose my groupmates or my problem I am solving. And almost always I can choose my way to solve the problem.” This sentiment of ownership was further highlighted by another student: “...you are in control of your projects.”

Regarding aspects of the course that students were dissatisfied with, they mentioned that assignments and writing tasks consumed a lot of time. For example, one student expressed their lack of understanding of the purpose of assignments: “The only thing that I disliked about the class was that there were hard assignments and I needed more explanation on things. Things like questions we had to answer didn’t make sense to me.” Another student commented on the excessive amount of writing: “...While I will agree that in the real-world documentation and writing is critically important, I feel this class takes that a bit too far...” Moreover, students felt that too much time was spent on each project. They mentioned, “I did not like how we spent most of the year on 2 projects,” and “Spending so much time on one project meant we couldn’t do much else.”

RQ2: High school engineering course’s impact on career interest

To answer this question, students’ self-reported career interests were classified into three categories: “Engineering”, “STEM but not engineering”, and “Not STEM”. Table 3 presents the frequencies for each category and the p-value. Within the “Engineering” category, there was an increase in frequency from 26% to 35%. This increase was statistically significant ($p = 0.008 < 0.01$), underscoring a marked increase in interest in the engineering field after taking the e4usa course. Conversely, in the “STEM but not engineering” category, the count decreased from 120 (30%) in the pretest to 81 (27%) in the posttest. Similarly, in the case of “Not STEM”, the count decreased from 115 (29%) to 91 (31%). However, the p-value suggested that the observed decline in interest in “STEM but not engineering” and “Not STEM” fields were not statistically significant.

Table 3. Distribution of Students’ Professional Aspirations.

Category	**Pretest (n=402)**		**Posttest (n=296)**		**Pre-post**
	Count	Freq (%)	Count	Freq (%)	P-value
Engineering	105	26	105	35	0.008**
STEM but not engineering	120	30	81	27	0.474
Not STEM	115	29	91	31	0.541

Note: Some students expressed career aspirations that spanned multiple categories. A P-value less than 0.01 is flagged with 2 stars (**).

Upon further analysis, the results indicated a statistically significant increase for female students in the field of engineering ($p = 0.037 < 0.05$). Male students and non-binary students did not show significant changes across all fields. Table 4 displays the p-value of the chi-square tests.

Table 4. Chi-square Tests on Students' Professional Aspirations across Gender.

Category	**Pre-post p-value**		
	Male	Female	Non-binary
Engineering	0.068	0.037*	0.186
STEM but not engineering	0.506	0.609	0.513
Not STEM	0.934	0.203	0.350

Note: Some students expressed career aspirations that spanned multiple categories. A P-value less than 0.05 is flagged with 1 stars (*).

Overall, the quantitative data suggested a significant increase in interest in engineering in the post-test, especially for female students.

Discussion

The emergent themes highlight high school students' preference for hands-on, flexible, and creative educational experiences. Prior research has identified hands-on activities, collaboration with peers, and opportunities to express creativity as engaging aspects of high school courses. The engineering curriculum is inherently suited to cater to these needs [17], [18]. The varying opinions on teamwork are consistent with prior research [6], [19]. Teamwork could lead to positive experiences but it could also be challenging when one/more team members fail to do their part. All pre-college learners should be exposed to team-based learning experiences to better prepare them for college education as well as future careers. Positive team-based experiences are often suggested as an avenue to promote inclusive learning [20]. There is an implication for the teachers to facilitate teamwork and support students in a manner that leads to positive experiences.

Moreover, students' initial disciplinary interests can influence the stability of their interest in pursuing a STEM career [21]. Our quantitative results revealed that high school students who participated in engineering courses demonstrated an inclination to consider a career in engineering, which aligned with prior findings. What is noteworthy is the statistically significant increase for female students post e4usa course. Previous work has shown that high school girls tend to perceive engineering as unsuitable for them, with limited encouragement for them to pursue this field [22]. Several studies have shown that despite performing well in middle schools, young women's interest in STEM, particularly engineering, drops off as they enter high school [21], [23]. Gender stereotyping, stereotype threats, and classroom experiences have been found to negatively influence their aspirations toward engineering [24], [25]. However, pre-college engineering education efforts to increase female participation in high school engineering programs have proven beneficial in encouraging their entry into the engineering field [4].

The study provides useful insights in the area of pre-college engineering education research. However, it is crucial to clarify that this study does not assert a causal relationship between participation in engineering courses and the consideration of a career in engineering. Future research is needed to further investigate this potential correlation. Our future plans also include further examination of SCCT's models of interest development and career choice through quantitative analysis. Efforts are underway to track e4usa alumni through their higher education programs and/or career choices.

Overall, the study offers suggestions for engaging high school engineering curricula and explores their impact on students' career choices. The results of this study have implications beyond the program context that inform teacher practices as well as future research. Understanding the characteristics of high school engineering courses for student engagement is crucial for improving the engineering education environment. Such insights could reshape pre-college engineering programs, promote diversity, and boost student career prospects considering engineering recruitment and retention.

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