



Understanding High School Student Experiences in an Engineering Course Designed For All (Fundamental, Diversity)

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Abstract

Pre-college engineering education still struggles to implement curricula that engage a diverse range of students. Engineering for US All (e4usa) aims to fill this gap through a course that demystifies engineering while catering to a broad range of students. This paper examines the influence of the e4usa course on students' engagement with engineering design, and their understanding of engineering as a potential future educational and career pathway. Focus group sessions were conducted with students from 12 participating schools during the 2020-21 school year to examine how their interests and understanding of engineering were influenced by the course. There were four main question categories for the focus groups, including: (1) students' perceptions of engineering, (2) engagement in the e4usa course, (3) influences of the e4usa course, and (4) experiences as a female in engineering. Focus group data were analyzed using open coding and constant comparison methods. Themes emerged from each of the main question categories, giving insight into students' experiences in the e4usa course. Understanding student experiences in the e4usa course has the potential to impact the future design of pre-college engineering experiences that can lead to a more diverse engineering workforce.

Introduction

Pre-college engineering education as a subject is relatively new to the United States' (US) education system [1]. A small number of pre-college engineering curricula were developed in the mid-1990s with the purpose of motivating students to pursue engineering careers [2]. These pre-college engineering courses have implications on other subjects and skills, including students' technological literacy, problem solving abilities, understanding of science and math applications, and exposure to engineering as a career [1, 2]. The National Academy of Engineering and the National Research Council Center for Education created a Committee on K–12 Engineering Education to address the instruction of pre-college engineering curricula. The committee recognized the need to create curriculum and programs to appeal to a greater diversity of students [1]. Several million K–12 students have now experienced some formal engineering education [1].

Students from cultures and groups underrepresented in STEM may experience more trouble navigating the differences between their home culture and culture of science than students from well-represented groups [3, 4]. This can lead to difficulties in STEM achievement, even when there is existing interest [5]. For female learners in particular, developing and retaining their interest in the STEM classroom is critical to diversifying the engineering workforce [6]. Women are still underrepresented in the STEM workforce, yet a diverse pool of talent with strong STEM knowledge and skills is vital for maintaining the US innovation base [7, 8]. The National Science Foundation (NSF) funded the Engineering for US All (e4usa) project in 2018 partly in recognition of this need. The goal of e4usa is to create an inclusive engineering course that demystifies engineering for all secondary students [9]. The curriculum was intentionally developed to empower, engage, and excite all students through a built awareness of engineering in everyday life, demonstrated diversity of engineers, and an emphasis on the societal embeddedness of engineering [10]. Pre-college students enrolled in the e4usa course learn about engineering principles, skills, and practices through hands-on engineering design projects that are embedded in students' local contexts.

The purpose of this study is to examine the influence of e4usa's course on participating students. The specific research questions addressed are: (1) What perceptions do students have about engineering after having participated in the e4usa course? (2) What aspects of the e4usa course did students find engaging? (3) What influences did the e4usa course have on students' interests in engineering? (4) What were the specific experiences of female students enrolled in the e4usa course?

Methods

Context

This study is a part of a larger NSF-funded umbrella project, e4usa, which began in 2018. The goal is to create an inclusive engineering curriculum and demystify engineering for

secondary students and teachers [9]. The course seeks to build a foundation of professional skills through engineering design experiences for all students- whether interested in engineering or not [11]. The curriculum taught in the e4usa course cumulates to build students' awareness of engineering in everyday life, the diversity of engineers, and how engineering is embedded in society [10]. Students in this course engage in various collaborative projects throughout each unit. Units 1 and 2 teach students how engineering is embedded in society. In Units 3 and 4, students learn about engineering as human-centered and responsive. In these units, students work with community partners to identify a need in their local community and plan, design, create, and present a prototype based on the defined need. Units 5 and 6 teach students that engineering is iterative and intentional. Students work together to analyze community partners' feedback and create hybrid solutions of their teams' designs. Units 7 and 8 provide a culminating experience, teaching students that engineering is personal and reflective. In these units, students choose an engineering project personal to them and work in teams to present their solutions.

Participants

Students of 12 schools across seven US states participated in the study during the 2020-21 school year. Schools were co-ed (n = 7), all girls (n = 5), public (n = 6), independent (n = 6), urban (n = 3), suburban (n = 6), and rural (n = 3). There were a total of 107 students who participated in the focus groups; 57 students from five schools during the Fall 2020 term and 50 students from the remaining seven schools during the Spring 2021 term. The sample was 69% female.

Data Collection and Analysis

Semi-structured focus groups were conducted virtually at each of the schools. The focus group questions concentrated around the four research questions: students' perceptions of engineering, engagement in the e4usa course, influences of the e4usa course, and experiences as a female in engineering.

To analyze the data, focus group transcripts were first checked in order to ensure their accuracy. The transcripts were then uploaded into Dedoose, an online qualitative analysis tool [12]. Thematic analysis was conducted with open coding and the constant comparison method [13]. The iterative coding continued until the possibility of new codes had been exhausted. Excerpts in the transcript were compared to others' information within the same transcript as well as across other transcripts to find commonalities and major themes. This analysis was conducted separately by two teams for the fall and spring focus group sessions. Each team created a codebook with corresponding definitions and example excerpts from the transcripts. The project teams then deliberated to merge common codes, resolve differences, and consolidate final codes collectively.

Results

Results converged around four emergent themes identified from each of the research questions. The question categories (as defined by the research questions), their descriptions, emergent themes, and illustrative quotes are presented in Table 1.

Table 1

Emergent themes that characterize pre-college students' experiences

Research Questions	Description	Emergent Themes and Categories	Illustrative Quote
Perceptions of engineering	New or changed aspects of students' personal comprehension of engineering as a professional field resulting from the course.	community impact, engineering is for everyone, problem solving	“What we did in this course made me really intrigued into what other [more advanced] courses could be like- college classes or classes for higher grade levels. And I think that those experiences combined with this one could help me see what kind of engineer I could be.”
Engagement	Features that made the course enjoyable and appealing to the students.	hands-on projects, course content, collaboration, creativity	“I really like being able to collaborate like with my peers, and like my friends and being able to work on projects together. So I really like that aspect of engineering that we can team up and not just have our own ideas, but like the ideas of the other people in the classroom.”

Research Questions	Description	Emergent Themes and Categories	Illustrative Quote
Influences of the course	The course's impact on students' interest in engineering and future plans.	curiosity about engineering, desire to pursue engineering, gained interest and confidence to pursue engineering, reinforced engineering knowledge, learned about: coding, the engineering design process, physics,	"I do think this course has definitely sparked my interest [in] engineering and made me more interested in the subject because all of the other science classes that I took before were never really hands-on. It showed me this whole new, different aspect of science. I thought that was really interesting and engaging."
Experiences as a female learner	Female learners' experiences being a part of the e4usa course.	challenges faced due to marginalized identity, opportunities for females, teacher support, female support network	"I think maybe lingering disbelief in the abilities of a female but that's, you know, fading now. So thankfully, still kind of there, though. But we got this, we can do it."

RQ 1: New or changing perceptions of engineering

The first research question captures students' new or changing beliefs about the field of engineering. Emergent themes include statements describing what engineers do and how engineering applies to everyone.

Students described how the projects they participated in throughout the course increased their understanding of the role of an engineer. One student mentioned, "[We've] gone over some topics about what comes next, like what happens in the field of engineering. And I also think that being able to work on the hands-on projects kind of gives us an idea of what they do, and the thinking that goes behind each project, like what tools you need, but also how you're going to put those items together and make something new." This example demonstrates how the e4usa course increased their understanding of what engineers do through the course's projects.

Many students expressed how the course helped them to see how engineering applies to other fields and real world applications. One student remarked. "...in a lot of different courses that you take, you kind of wonder to yourself, 'How would I actually use this in real life?' Or, 'How does this apply to like things I see every day?' And I think engineering, like, had the greatest impact, because you actually get to see how it works in real life in real time. So I feel, like, that real life application is really unique to the course. And helps you see the world differently." This student excerpt demonstrates how the e4usa course was unique relative to other

courses students take in high school and that the course made explicit the connections to out-of-class scenarios. Students developed an understanding of how prevalent engineering is in the world and its impact on a multitude of other disciplines.

Students also expressed that they were able to learn how engineering can be for everyone. One student noted, “I think a big part of this course was the fact that anyone can be an engineer and almost everything has aspects of engineering in it.” Students expressed a belief that the course helped them to realize the broad applicability of engineering that can encompass aspects that accommodate anyone’s interests.

RQ2: Engaging aspects of the course

Engagement emerged as another prominent theme. In particular, students expressed their enjoyment from working on hands-on projects, collaborating with other classmates, learning the course content, and having an opportunity to express creativity.

Students expressed that having the ability to participate in hands-on engineering projects was more enjoyable for them than delivered lessons. Students enjoyed working through the engineering design process. As one student described, “I feel like what helped me the most was the end engineering project, because it was really hands-on and we had to figure out a problem we wanted to solve and then solve it ourselves. And through the process, we interviewed some people, and really went through the engineering design process- unlike some of our other projects, where we hypothetically thought about it more. So that I think really helped me.” Students also expressed their enjoyment from the problem solving aspect of the hands-on project.

Students also enjoyed working on a team in order to complete a certain task and achieve a common goal, as opposed to working on a project alone. One student stated, “I really like being able to collaborate like with my peers, and my friends and being able to work on projects together. So I really like that aspect of engineering that we can like team up and not just have our own ideas, but the ideas of the other people in the classroom.” Students recognized the benefits of collaboration as it allowed them to see different perspectives and ideas.

Students also expressed how they found the content of the course to be more engaging than other courses. It seemed like it was easier for them to stay focused and learn the material of the course, because they found the content enjoyable and engaging. The following quote captures this sentiment, “...usually in other classes I would lose focus and I wouldn't really pay attention, now but this class, it just kept me like, kept my eyes on the screen, and I took notes of what I was learning so I can go back on it, and re-think about it.”

Another source of students’ enjoyment from the course came from having the opportunity to be creative. As one student mentioned “I like the curriculum... I really liked the creative component. That's the reason why I picked this course, because I wanted a more project based course.” Not only did students enjoy working on projects throughout the course, but they enjoyed that the projects allowed them to be creative in order to accomplish the intended goals. Overall, students found enjoyment from the course in their ability to engage in hands-on engineering projects through problem solving, creativity, and collaboration.

RQ3: Influence of the course on student interests toward engineering

The e4usa course seemed to influence students' curiosity about engineering, desire to explore engineering, and their interest and confidence in pursuing engineering. Students' desires pertaining to engineering were affected by the course in different ways. Some students talked about engineering as a potential education pathway as well as a career option in the future. Students stated that they aspired to pursue engineering during their higher education after their involvement in e4usa. One student stated, "what we did in this course, it made me really intrigued into what other bigger courses could be- college classes or classes for higher grade levels. And I think that those experiences combined with this one could help me see what kind of engineer I could be." As illustrated by this student and others, e4usa's course influenced their interest to participate in further engineering courses. Since this course was many students' first introduction into engineering, retaining initial interest and gaining further confidence in engineering is important for encouraging students to pursue engineering in higher education.

A few students also considered engineering as a potential career pathway. One student explained, "I could definitely see myself pursuing a career in engineering after experiencing and going through these projects and how much I enjoyed going through the process and finding out all these different things that like all the constraints and all the things that go into like a project and creating a solution." For this student, participating in the engineering design process throughout the course, helped reinforce their engineering knowledge and increase interest in engineering, resulting in a further desire to pursue engineering. Overall, the course broadened students' understanding about career paths within engineering.

RQ4: Female student experiences with the course

Female students in e4usa noted different experiences in the engineering classroom due to their gender identity. Many female students recounted a positive environment as well as support structures that added value to their learning experience. Four sub-themes emerged that describe female learners' experiences in the engineering classroom: (1) challenges faced due to marginalized identity, (2) specific opportunities for females, (3) female support network, and (4) teacher support.

Female students recognized engineering as a male-dominated field and acknowledged challenges they may encounter in engineering classrooms and the engineering workplace. A female student enrolled in an all-girls school remarked, "I think people have different expectations for men and women, the field of engineering. And I think that being able to learn in a classroom with all girls, it was really helpful because I was surrounded by people who think like me, and that I could talk to about it." This student recognized the gender disparity existing for women in engineering, but resonated on how the female support network that existed at her school helped increase her self-efficacy in engineering.

A discussion regarding possible challenges or roadblocks students foresee in becoming engineers led to conversations around the lack of representation in engineering. One student

stated, “I was thinking about the projects we did in the beginning of the year, the female engineering ones. I didn't have the easiest time finding a female engineer who also happens to be a person of color, because I wanted to include that in my presentation... It's not like there weren't any but it wasn't the easiest. So it's good that there are courses like this across the nation and across the world that can provide females with these resources to hopefully open up the engineering world to them, so that they can pursue careers in this area.” This particular student recognized the need for a broadened representation of intersectional identities (e.g. women and people of color). Many female students resonated with this feeling and described a lingering lack of confidence in their engineering abilities associated with these marginalized identities. This emphasizes the need for support structures and representation of marginalized identities in the engineering classroom to encourage and engage female students.

Female students also described opportunities available for female learners in the e4usa course that they had not experienced in other courses. These opportunities led to increased personal and professional growth through building confidence in engineering ability and leadership. Some students noted participating in the e4usa course allowed them to gain confidence in their engineering skills. For example, one student said, “I think that it's really nice that the engineering program is really focused on the girls because it allows them to really, like, improve their knowledge on the curriculum, like engineering itself and it really allows them to really participate instead of, you know, someone else taking over, but obviously that's going to change in the future, so, and today, so I mean, just kind of when it comes to like learning.” Although not explicitly stated, the phrase “someone else taking over” hinted at female voices being drowned out. e4usa’s curriculum created for *all* learners gave female students the ability to be an active participant in their learning.

Female students felt that their voices were heard in this course, which encouraged further participation and increased knowledge in engineering. Several students described how this course created a comfortable environment, allowing them to brainstorm ideas and collaborate. One student stated, “I think that this class and the environment that we're in is definitely supportive. I like that we can all talk to each other and feel comfortable bouncing ideas off of one another, or brainstorming with each other. It's really helpful to be able to have people that you can talk to about your project, and not have to be in it completely alone.” One student elaborated on this feeling of comfortability, when she said, “I think that there's a kind of genial camaraderie that develops between students when they work on tackling a problem together from start to finish. And I think that's definitely one of the more positive aspects of the course.” The camaraderie of females in e4usa’s course helped encourage and support the female learners in their learning experience.

Teacher support in the engineering classroom also aided in female students' learning and confidence. Many students described how continued support from teachers, when solving engineering problems, encouraged them to persevere through obstacles. A student shared, “[TEACHER NAME] is always there to help us and set us on the right path... She was always there as a support system, or someone to look to when you needed a little bit of help. I think that

was really helpful, especially when things were not going the right way.” For students in the e4usa course, a teacher that they could “look up to” and receive continued help from, encouraged them to persist during difficult assignments.

Discussion, Implications, and Future Work

Understanding the influences of curriculum has the potential to impact the future design of pre-college engineering experiences that can lead to a more diverse body of engineers and improved career outcomes for those with exposure to pre-college engineering curriculum. The results provide insights into the relationship between curriculum created for all and the wider impacts on student’s career choices and female’s experiences in engineering.

The emergent themes from students’ new or changing perceptions of engineering supports the conclusions of previous research, in which the promotion of collaborative learning and creative problem solving aid in the better connection to engineering applications [14, 15]. Through the projects, students expressed a broadened understanding of the role of an engineer and engineering applications. Students expressed changed perceptions of engineering; that anyone can be an engineer. Engagement in the course may have led to increased excitement and shifts in perceptions of engineering.

The emergent themes indicate that many students do not fully understand the meaning of engineering. Engineering is used (and often perceived) as a broad term to describe a profession about building things [16]. In the focus groups, students expressed that they developed a better understanding of where engineering is used and how an engineering mindset can be applied. Some students also remarked that with this broadened understanding of engineering, they realized that anyone can be an engineer. Courses like e4usa are needed to engage all students in engineering. a broadened understanding of what engineering is and how it can be applied, introduces students to engineering who may have not previously expressed interest in the subject. This is especially important in order to increase diversity in the engineering field.

Moreover, regardless of their future career path, an engineering mindset can be applied in other jobs. Students identified the hands-on activities in the course, collaboration with peers, and opportunities to express creativity as engaging aspects of the course. Students expressed more interest and enjoyment in the course material because of these engaging aspects embedded into the e4usa course. Hands-on experiences have been found to enhance engineering curricula through increased motivation and retention of students, particularly those with little exposure to engineering [17]. Such outcomes could fulfill e4usa’s goal of reaching a broad range of students regardless of background.

The emergent themes from experiences as a female learner broadens initial research regarding the decline in females in STEM courses after middle school [6]. The female participants in this study have already recognized barriers to entry in engineering before beginning higher education. Since high school is usually the first time that students have more autonomy in choosing their course schedule [18], the awareness of future barriers could be a

factor that contributes to some girls' decisions to not pursue further STEM classes in high school. However, the findings from this research do shed light on support factors that were helpful to females in the e4usa course, including having teacher support and a female support network in the class, as well as the availability of broadened opportunities (e.g. leadership opportunities). These insights could be used to create support systems that aid in the recruitment and retention of high school girls into engineering. This is especially important, as early exposure to engineering in high school is one of the strongest predictors for students pursuing engineering in higher education [19].

Areas for future research

Pre-college learning environments that encourage and empower all students is crucial to broadening diversity, equity, and inclusion in STEM. Our future work may further explore girls' experiences in e4usa's course, as well as other schools offering this course that cater to marginalized identities. This includes, but is not limited to, "alternative" schools, rural/remote community schools, and schools for students with disabilities. Understanding these marginalized experiences in the pre-college engineering classroom and areas for improvement/further support, has implications for not only e4usa's course, but other pre-college engineering courses as well.

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