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Understanding the Anchors Associated with Secondary School Students' Engineering Design Experiences*

ADAM R. CARBERRY[1], MEDHA DALAL[1] and OLUSHOLA EMIOLA-OWOLABI[2]
[1] Arizona State University, Mesa, AZ 85212, USA. E-mail: adam.carberry@asu.edu, medha.dalal@asu.edu
[2] Morgan State University, Baltimore, Maryland, MD 21251, USA. E-mail: olemi2@morgan.edu

Many students do not truly encounter engineering education during their school years despite numerous calls to increase focus on engineering-centric knowledge and skills in pre-college education. This study uses a Social Cognitive Career Theory framing to examine the nuanced experiences of pre-college students who learned the engineering design process through multiple, progressively complex project experiences in an introductory engineering course designed for all. Data was collected from 80 students within eight schools across the United States using multiple focus groups. Iterative thematic analysis revealed four themes that collectively depict how design experiences provide an anchor or a comprehensive knowledge base for engineering pathways. The study provides insights into the complex interplay of learning activities and wider educational contexts that influence students' higher education and career choices. Understanding the anchors associated with students' design experiences has the potential to impact future motivation and design of pre-college engineering experiences that can lead to improved student recruitment and retention in higher education.

Keywords: pre-college engineering education; engineering design; prototyping; social cognitive career theory

1. Introduction

Engineering touches every aspect of human life yet engineering as a subject in pre-college education has only seen limited inclusion [1]. Numerous college and workforce readiness reports support the idea that the pre-college educational enterprise should increasingly focus on the teaching, learning, and practice of engineering-centric knowledge, skills, and abilities (e.g., problem-solving, design thinking, prototyping, and teamwork) that cut across a broad range of 21st century careers [1–3]. Many schools have addressed these calls through the integration of engineering as part of science, technology, engineering, and/or mathematics (STEM) classes [4]. This is due in part to efforts to embed engineering in pre-college science standards [5] and an overall lack of agreement as to what constitutes engineering teaching and learning in pre-college education [6–8]. The consequence of these actions is that the majority of students still do not truly encounter formal engineering education during their pre-college school years, which severely limits students' ability to gauge their understanding of and interests in engineering. Steps need to be taken to address the growing need to empower young people to mature into informed innovators to solve the tough challenges the world is facing now and will face in the future [2]. This will take a monumental effort to find ways to explicitly incorporate engineering into an already overcrowded pre-college curriculum.

The current study was undertaken as part of a larger National Science Foundation funded umbrella project, Engineering For Us All (e4usa), which began in 2018. The goal of e4usa is to 'demystify' engineering for secondary school students and teachers through the creation of an all-inclusive engineering curriculum. A unique course was designed and developed with all students in mind to promote the development of students' professional skills through a series of engineering design experiences. The course is built on specific technological foundations and does not provide a survey of engineering disciplines. The focus instead is to connect all schools, teachers, and students, regardless of background, to engineering using the following objectives: (1) introduce the engineering design process to all students including those who may not be predisposed to pursue engineering; (2) develop professional skills, such as interdisciplinary thinking, creativity, innovation, evaluation, and collaboration, that cross-cut a broad range of fields; (3) create a bridge for students who may want to select engineering majors in higher education; and (4) make engineering more inclusive and accessible to secondary school educators and students, particularly those in underserved regions of the United States. These objectives were initially informed by the First-Year Engineering Classification Scheme [9], a taxonomy of all objectives and best practices that could be found in first-year, introduction to engineering courses in general-admit engineering programs. Later conceptualization followed a kick-off workshop that brought together stakeholders across the entire engineering

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and engineering education ecosystem to determine what should be prioritized at the secondary level. The result was a new engineering offering unlike most, if not all, other pre-college engineering education and outreach programs [10, 11].

The intent behind the course is not to produce more engineers or introduce rudimentary engineering-specific skills, but to introduce engineering as a professional field and a discipline within higher education that is connected to everyday life. This is one area where the e4usa curriculum differs from first-year engineering courses. The focus is on imparting engineering literacy and engineering-centric skills through design experiences rather than engineering content [12]. This approach is framed by four threads: discovering engineering, engineering in society, engineering professional skills, and engineering design. These threads are woven throughout the curriculum and imparted to students through a project-based approach that spans eight units. The curriculum is designed as four 9-week quarters with a target of approximately 200 minutes per week of instruction. The focus of the first quarter (Units 1 & 2) is to introduce 'engineering' as a discipline that influences almost everything we see and do in our daily lives. The second quarter (Units 3 & 4) invites students to select and research a local problem. Students then brainstorm, sketch, and prototype solutions in collaboration with stakeholders in their local community. The third quarter (Units 5 & 6) focuses on a design for a more global problem. Lessons lead students to identify a global issue and a local problem that is associated with the global issue to build, test, and optimize a prototype. The final quarter (Units 7 & 8) provides students with opportunities to examine their day-to-day lives to find problems that can be tackled by a student team. Unit 7 once again leads students through each step of the design process to develop a prototype solution. Unit 8 wraps up the course with reflection activities and assignments. The sum of the course offers students opportunities to 'think like an engineer,' while developing and practicing engineering design and professional skills multiple times via progressively more open-ended and complex project experiences.

The course was piloted in 2019–2020 in nine schools across the nation. The objective of this study within the context of e4usa is threefold: (1) examine the nuances and sources of positive and negative student experiences relating to design activities (e.g., sketching, drafting, prototyping, and producing artifacts), (2) understand the anchors associated with these design experiences that may lead high school students to pursue engineering pathways, and (3) to further scholarship efforts supporting the inclusion of engineering as a compulsory subject in secondary education. The lexical meaning of the term 'anchor' is to hold something securely or an object that is used to hold something securely. Learning Sciences uses the term 'anchor' to imply an essential question or mastery objective that provides students with a comprehensive knowledge base [13]. Anchors fill in the space between theory and practice and help students "develop the necessary information, ability and confidence for being an individual that can think independently and a problem solver at the same time." [14, p. 60]. Our purpose behind using the term "understanding anchors" is to imply that the design experiences embedded in e4usa provide the pragmatic basis for high school students that fills in the space regarding what is engineering and prepares them with a basic yet comprehensive knowledge base to set future education and career goals.

2. Literature Review

2.1 Pre-college Engineering Education

Engineering has not traditionally been a subject in pre-college education in the United States [1]. Several trends in the early 2000 (e.g., lower national achievement in sciences and mathematics among pre-college students, declining enrollment numbers in engineering programs, and the need for improved technological literacy) brought the advancement of engineering in pre-college education to the forefront [15, 16]. The National Academy of Engineering and the National Research Council Center for Education established a Committee on K–12 Engineering Education in 2006 to begin to address the national need for pre-college engineering education [1]. The committee recommended integration of engineering with other subjects and infusion of engineering learning goals into standards for other disciplines (e.g., science). The committee also suggested three general tenets for pre-college engineering education: (1) emphasis on engineering design as an approach to identifying and solving problems, (2) incorporation of analysis and modeling skills with developmentally appropriate mathematics, science, and technology knowledge, and (3) promotion of engineering habits of mind, including skills of creativity, collaboration, communication, and ethics. These tenets provided the foundation for the Next Generation Science Standards (NGSS), which promoted the role of engineering in science education [17] and raised the engineering design process to the "same level as scientific inquiry" [18, Appendix I, p. 1].

The incorporation of engineering into science standards has encouraged some public, charter, and parochial schools to teach engineering as its own separate subject [19, 20]. Such efforts have been arduous because work remains to establish common ground and a clear meaning of pre-college engineering education as it relates to curriculum and student outcomes [7]. According to the *K-12 Education: Understanding the Status and Improving the Prospects Report*, "The absence of standards or an agreed upon framework for organizing and sequencing the essential knowledge and skills to be developed through engineering education at the elementary and secondary school levels limits our ability to develop a comprehensive definition of K-12 engineering education" [1, p. 151]. Efforts have recently started to address the need for a framework and set of standards for pre-college engineering education. The recently released, *Framework for P-12 Engineering Learning*, emphasizes engineering literacy for every student through the confluence of engineering knowledge (e.g., engineering sciences, engineering mathematics, and technical applications), habits (e.g., persistence, creativity, collaboration) and practices (e.g., engineering design, materials processing, quantitative analysis, and professionalism) [21]. The practice of engineering design was deemed a crucial competence in equipping students to think 'like an engineer' and develop skills of problem-solving, persistence, creativity, innovation, collaboration, and inter-disciplinary thinking.

2.2 Focus and Importance of Engineering Design in Pre-college Engineering Education

Engineering design can serve as both a learning process and a means of learning in pre-college engineering education [22]. The fundamental characteristics of engineering design offers a unifying activity that can be taught throughout several pre-college grade levels, either integrated with or separate from other subjects [23]. Teachers can engage students in solving 'real' engineering problems without expecting comprehensive knowledge of engineering concepts [24]. This approach can be appealing to students who have experienced difficulty in traditional science subjects [25] because it provides students with bountiful opportunities to develop and practice technical and professional skills, while systematically solving a problem [26, 27]. The students practice design using their imaginations, technical knowledge, creativity, and collaboration skills, while drawing on and learning to apply ways of thinking across various stages of the engineering design process [27–29].

Several studies have looked at the importance and pedagogical effectiveness of engineering design experiences for pre-college students. This work has concluded that well-structured design experiences can serve as an excellent mechanism for introducing students to engineering [22, 27, 30]. Students introduced to engineering through design learn the process, gain foundational content knowledge of the field, navigate trade-offs between criteria and constraints, evaluate projected solutions, learn to accept ambiguity, value different perspectives, create prototypes, develop a growth mindset, and learn to communicate with others [27, 31–35]. Key to achieving these benefits is a recognition that design is an inherently social venture involving teamwork, collaboration, and communication [22, 28], while also requiring an understanding of people and culture [36]. Learning engineering design in a classroom environment translates into a social-cognitive experience for students.

2.3 Social Cognitive Career Theory

Social Cognitive Career Theory (SCCT) provides a coherent conceptual framework for understanding how engineering design experiences are translated into interest in and an intent to pursue engineering activities in the future through self-efficacy and outcome expectations [37]. SCCT posits that students develop interest in engineering when they hold strong beliefs about their ability to perform (self-efficacy), and positive beliefs associated with pursuing it (e.g., outcome expectations). The theory suggests that environmental and contextual elements combined with learning experiences impact both outcome expectations and self-efficacy to then influence interests, intents, and decisions [38, 39]. Context can act as a barrier or support to influence the interests and goals of individuals [40].

Several studies have investigated students' design experiences in undergraduate engineering courses using SCCT [41–43], but little is known about such experiences in pre-college settings [16, 44]. There are many outreach programs and robotics clubs that are focused on engineering exposure for high school students [45]. Research in such contexts has focused on assessing students' perceptions, attitudes, and beliefs regarding engineering as a profession using survey methods [46, 47]. The survey research suggests that hands-on engineering design projects have a positive impact on students' engineering perceptions and choices [44]. Prior research has also demonstrated that there is a complex interplay of learning activities and wider educational contexts that influence student experiences [48]. It is critical to further understand the drivers and nuanced experiences behind the positive impact, especially when there are numerous recent calls to encourage more young people to consider engineering as a career pathway [1, 2].

This study aims to address this need, to understand the nuances and sources of positive and negative experiences relating to design activities (e.g., sketching, drafting, prototyping, and producing artifacts). We look to understand what experiences provide anchors of persistence for students, specifically in pre-college settings.

3. Methods

3.1 Sample and Data Collection

Participants were a subset of secondary school students (9th–12th grades, N = 470) who had enrolled in the e4usa course during the 2019–20 academic year. Eight of the total nine pilot schools, public (n = 7) and charter (n = 1), agreed to participate in research. The public schools were classified as being large urban (n = 2), large suburban (n = 4), and remote rural (n = 1) [49]. The charter school was classified as a large suburban [49]. Participating high schools were spread across the United States in five states as well as Washington, D.C. (Table 1).

The e4usa course did not require teachers to use specific technological tools such as computer assisted design (CAD), but teachers had the flexibility to use tools as they desired. The flexible design of the course also allowed teachers to teach the prototyping process differently, including pen and paper sketches, cardboard mock-ups, and virtual artifacts. The prototype forms were often influenced by classroom instruction modality during the COVID-19 disruption and other embedded aspects selected by the teachers (e.g., CAD). Early units are designed to engage students in designing water filters, designing a wallet for a classmate, and addressing a local community need. Teachers often collaborated with local community partners or other classrooms to bring in clients and provide authentic prototype creation experiences for students. Some example projects included designing toys for animals at a local zoo, creating a keyguard for elementary school students with disabilities, designing multiple soundproofing solutions for the school's music room, and designing personal protective equipment shields to prevent COVID-19 exposure. The curriculum is scaffolded so that students get to prototype and test their solutions, with some room for iteration.

Teachers solicited students' participation in the research by collecting student assent and parental consent forms. Each teacher then recruited and selected four to eight students from the consented list for focus group participation. Teachers were encouraged to recruit participants heterogeneously across gender, race/ethnicity, and achievement levels. Two focus group sessions were conducted at the end of the Fall in eight schools and at the end of Spring in six schools. Fall term focus groups were conducted in-person, while Spring term focus groups were conducted online due to the COVID-19 disruption. Some of the participating schools' administration decided to send curricular materials to students at home and not to re-open for online classes in late Spring due to technology access issues faced by students. This prevented the Spring focus group from occurring in two of the eight schools. The focus group questions were designed to understand nuances of students' experiences specifically around design-related activities and interests in the e4usa classroom. Two members of the project team conducted all focus groups using the same set of questions for both the Fall and Spring sessions. Students shared their experiences while reflecting on what they learned and the challenges they faced. Teachers were requested to select a different set of students for the Spring session to ensure a wider coverage of student voices and perspectives. A total of 80 students (40 females) participated across both sets of focus groups; 47 students (22 females) during the Fall session and 33 students (18 females) during the Spring session (Table 1). Spring term was impacted by the COVID-19 pandemic, which provided a new set of experiences amidst challenges of distance learning and remote team environments that are also discussed. Demographic data beyond gender, including race, ethnicity, and socioeconomic status were not collected, but school level data was considered.

Table 1. Breakdown of participant numbers across schools

	Fall term focus groups		**Spring term focus groups**	
School location	**Female**	**Male**	**Female**	**Male**
Arizona (Urban)	2	2	4	1
Maryland (Suburban)	2	3	6	2
Virginia (Rural)	1	2	2	2
Washington D.C. (Urban)	1	4	N/A*	N/A
Pennsylvania (Suburban)	3	4	0	6
Tennessee (Suburban)	2	5	N/A	N/A
Maryland (Suburban)	6	2	5	0
Maryland (Suburban)	5	3	1	4

* N/A represents locations where focus groups were not conducted due to COVID-19 restrictions.

3.2 Data Analysis

Qualitative data analysis followed an inductive, two-cycle coding approach [50] that was informed by SCCT. Focus group transcripts were checked for accuracy and uploaded in Dedoose [51], an online tool used to facilitate coding and qualitative analysis. Two members of the research team conducted an initial round of coding going line-by-line through the transcript. Each of the meaning units were open coded while also looking for repeated instances of the underlying concepts across the meaning units and transcripts [52]. This process continued until coding saturation was reached and no more new codes were added with the analysis of the fifth transcript. Similar codes were then merged, and higher-level coding categories were created to capture the essential ideas underscored in the participant statements. This coding scheme was used by three other members of the project team to code three more transcripts from the Fall session looking out for any inconsistencies or discrepancies. Some code definitions were revised for further clarity based on the feedback. A few codes were further consolidated into higher level categories to reduce the number of codes. A codebook was created with the finalized codes and definitions. One member coded the remaining six, Spring session transcripts with the codebook and re-coded the initial eight, Fall session transcripts with the revised codebook. Credibility [53] and rigor were addressed by having approximately 30% of the data units across all transcripts coded by another member of the research team to test percentages of agreement; 81% agreement was found to be within the almost perfect range (81% to 100%) [54]. Finally, the codes were compared with each other and the constructs of SCCT to identify emergent themes.

3.3 Limitations

Any qualitative inquiry leads to the limitation of generalization. The goal of qualitative research is not to prove something through generalization, rather it is to develop the nuanced view of the experiences in varied contexts and grasp the potential contribution of these experiences to improve student learning and outcomes [55]. A small number of high schools participated in e4usa, and the findings cannot be transferred to the entire pre-college population. This study provides a useful contribution to an area of research with limited findings, namely secondary school students' engineering design experiences. The research team would have liked to gather data from students in all nine schools where the program was piloted, but research permission was not granted in a timely manner at one of the nine schools. It should also be noted that COVID-19 disruption prevented in-person learning in Spring, 2020, which affected the pacing of the e4usa curriculum. The curriculum could not be completed in its entirety by the end of the 2019–2020 school year in which this program began. The associated limitations undoubtedly hamper certain insights, but also led to a new set of student experiences through online or hybrid education modalities. The online learning mode was a very new experience for many high school students. This also affected student participation in the Spring focus groups where students either shied away from joining or encountered technology issues after committing to participate. This resulted in Spring focus groups being less diverse than Fall sessions in terms of participant demographics.

4. Results and Discussion

Results converged around four major themes (Table 2) that collectively depict how design experiences provide an anchor for engineering pathways: (1) prototyping and creating artifacts, (2) developing skills, (3) overcoming and learning from challenges, and (4) connecting to future plans. It should be noted that the terms 'students,' 'participants,' and 'participating students' are used interchangeably in the following subsections that expound upon each theme using subsumed codes, illustrative quotes, and a broad narrative citing literature.

Prototyping and Creating Artifacts: The greatest single influencer of the course on student learning and identity formation was the hands-on prototyping and artifact creation. One student specifically mentioned the freedom to ". . . do it like yourself like hands on. It's not like being explained to you rather than actually being able to do it yourself." The hands-on elements of the course clearly helped increase student engagement and confidence relative to other courses because, "The amount of hands-on work we get to do is infinitely more than every other class. It's so much more engaging." This approach led to increases in student confidence as exemplified by one student quote, "I feel more confident learning about engineering rather than other classes because I, here we go hands-on and we get to experience everything that we do instead of just talking about or just taking notes all day, so they don't lose our interest." Such hands-on work are examples of mastery experiences, which have been shown to be extremely important sources of self-efficacy beliefs [56, 57].

Hands-on prototyping and artifact creation allowed students to have more fun engaging with the concepts of the class because they were able to use the principles learned in real time and see how

Table 2. Emergent themes that characterize pre-college students' design experiences

Theme	Anchor	Subsumed Codes	Illustrative Quote
Prototyping and creating artifacts	Opportunities to learn from hands-on construction of physical things connected to real world applications.	Creating your own product, freedom to try out different things, open-ended assignments, brainstorming ideas for a product, seeing things through to the end, hands-on work, real world connection.	"It makes you feel better because you can look to yourself and be like oh, I made this, I'm actually proud of it, instead of being in front of a computer that did it for you."
Developing skills	Technical and professional skills developed and connected to future careers.	Communication, perseverance, time management, general problem-solving, organizational skills, learning about multiple solutions to a problem, teaming.	"When we're working with other people, everybody else with our own ideas, and they are really, really good, so we kind of learn how to integrate our ideas together."
Overcoming and learning from challenges	Persistence in the face of difficulties and/or failures.	Converting an idea into reality, self-guided nature of projects, stakeholder orientation, accepting failure, managing timeline, teamwork issues.	"With our group, we had to talk to the leader of the Parks and Recreation in our area, and contacting him, he wasn't always giving us what we wanted per se and not giving us the answers to the questions we were asking exactly how we envisioned him to answer. That was definitely a challenging part."
Connecting to future plans	Influence of engineering design experiences on student interest.	Awareness about careers in engineering, narrowing down choices, more prepared for future education, solidified interest in engineering.	"I feel like this class teaches you the basics. And once you've learned the basics of anything that you can always progress from where you're going. I feel like, yeah, as we grow older and we decided to go into engineering field, with, with the background and knowledge of what and how, what we've gained from this class, I feel like we'll be pretty good and set to learn more."

they did or did not work. This aspect was enhanced through opportunities to brainstorm ideas embedded in open-ended assignments. One student mentioned "the thing I like most about this course is that when we're given a project, we're not really limited to like our thoughts or ideas, we're limited only by like our materials. And then from there, we can just do any way of solving the problem that we want, as long as it actually solves the problem." These elements of e4usa are major pillars intended to allow students to elevate their learning beyond the classroom and see the real-world applications of the engineering design process. This approach has been highlighted for decades now as key to engineering curriculum reform [58] and is demonstrated through these findings as critical to pre-college student engineering experiences.

Developing Skills: Professional skills are as important as technical skills in an engineer's job [59], which has led undergraduate curricula [60, 61], and now pre-college curricula [62] to increase the focus on teaching professional skills. It was not surprising, based on the design of the e4usa curriculum, that participants focused discussions primarily around development of professional skills, including "learning to work as a group toward the project goal," "asking appropriate questions to the client to correctly understand their needs and requirements," and "learning to manage time and other organizational skills." Prior work has advised that students appreciate and develop professional skills better when learning experiences are embedded in the real-world contexts of design projects [63, 64], which was the structure for the e4usa curriculum.

Students spent much of their time during focus groups reflecting specifically on their teaming experiences. Collaborative design experiences put students in situations where they had to learn that "working with others is not easy but it is an important skill." One student noted, "If I could choose a team to help me with it, then I feel pretty confident. But if I have to do it myself, I feel less confident." The act of increased confidence came from the feeling that "...having teammates would help to cover some of my flaws." This finding supports the result of previous studies that have shown that teamwork positively influences students' engineering self-efficacy [28, 65, 66].

The benefit of working on engineering projects in teams went beyond confidence building. Students noted that, "Working with others to accomplish a goal is a very important skill," even when it involved working with ". . . people I don't really talk to a lot." These situations even lead to thoughts that this ". . . was really fun I guess." Particular focus was placed on recognizing that, ". . . there have been times working in a group in this class that have been kind of stressful and kind of hard to get through. But it's more like that learning process of being able to deal with the stress . . ." This led to an appreciation of the teaming experience even when challenges arose and an understanding that the benefits far outweigh any drawbacks or frustrations. Statements highlighting the value of teaming as a professional skill and recognizing the challenges associated with working in teams have been shown in previous studies [26, 27]. Such examples demonstrate students' ability to use their engineering design experiences to develop lifelong teaming skills that can be used in future education, work, or everyday life situations.

Embedded in discussions around teaming was a recognition of project management as a skill. The self-guided nature of the prototyping activities helped students understand the importance of practicing planning and management skills. One participant explained, "It's sort of like you have a week to finish this, and you have to go at your own pace. And sometimes I find myself doing things all the way at the last minute. It is like, it teaches you more like oh, and you should spread this out to make it a little bit easier. This teaches you how to use your time better."

Participants discussed how the engineering design process also provided a framework for solving problems in a variety of situations through a combination of technical and professional skills. Brainstorming taught participants how to use knowledge, experience, and their imagination in various ways to address problems. They learned how to select data, how to process data into useful information, and how to communicate and convey findings to peers. Modeling and prototyping helped students understand how to turn an idea into a working model or simulation, challenging them to understand and describe more deeply the features and limitations of their idea. Prototyping enabled participants to learn the value of failure and why redesign is a critical step. The ability to understand why their prototype was not performing well and using critical thinking with deductive reasoning to make a change to the design were highlighted as valuable skills they could take with them into pursuits of higher education as well as their future careers.

Overcoming and Learning from Challenges: Many drivers that led to positive experiences for students were also described as challenges. The open-ended, self-guided nature of projects, teamwork, and stakeholder orientation were prevalent elements that students described as challenging experiences. Participants enjoyed the open-ended nature of the course assignments and projects, but also felt the lack of teacher guidance led to more questions than answers because, "You're free to do it yourself and there's nobody really holding your hand through it. So if you don't know, like how to work and find the solution to the problem, you have to research it yourself, instead of asking a teacher like what do I do? How do I solve the problem?" This led to a need to accept failure as part of the engineering design process, which can be hard when, "Having it fail multiple times. It's a little nerve wracking, but somehow [you] push through this." Teamwork was cited as challenging when one or multiple students within a group failed to do their part. This led to comments like, "With bad groups it's like putting responsibility on other team members. And then worrying about whether they have done it or going back and seeing that they haven't done it. And then you know, I had to do extra work."

Understanding the stakeholder needs and communicating with clients were recognized as novel experiences for most participants, including those who had taken an engineering class previously. Such opportunities created challenges in that, "The customer base is what really impacted [us] because [we] hadn't seen that before and it was something new. It was like a little bit of a challenge, and at the same time it was like you have to accomplish the needs of a particular person, not just what you want the design to look like but what the person wants." Students realized that despite knowing what they wanted to do, "the fact of drawing it out and explaining it to other people that make it hard." This challenge could be exasperated by the limited materials students had available to them to complete their projects. In some instances, students were, ". . . limited in terms of materials, we can't always get a hold of materials that we need or really good materials, per se. Sometimes we have to just use basic things, like cardboard. We can't really use metal and stuff like that."

One specific challenge faced by these participants was the shift in modality from in-person to online as a result of the COVID-19 pandemic. This disruption added to the challenges faced by students. The remote learning environments involved in this project impacted students' access to peer group resources, tools, and materials, and amplified the challenges of collaboration. For example, one student said, "I feel like it was more difficult, like creating the actual project, like group projects online because we couldn't really work together as good when we created the project." Another commented, "Just having the actual resources because we're not at the workplace you don't have the extra resources to produce it anymore. So that was also like a big hit."

Data suggested that students were unhappy with remote learning, whether that meant working individually or working in teams online. Students who were working individually felt like they were, ". . . given projects that [were] a little bit less challenging than the ones we got before. Because there's a bunch of brains involved. So there's always somebody on the team that knows more about this and that so it gets you thinking even more. So most definitely we do miss working as a team." Students working in online teams repeatedly described the experience as difficult compared to in-person work because, "There was no longer like interpersonal, like, face-to-face talking to people and it kind of takes away some of the understanding. Like if I were to talk with [student name] about our animation project, I can't physically show her on my screen of what I was doing and I can't really explain it too well. They're just text. It's a lot better to do like face-to-face conversation. So communication kind of been, at least in my opinion took a hit." Online learning in pre-college contexts is a recent phenomenon [28]. Very little scholarship exists examining design experiences, student support, and effective delivery of remote engineering classes in pre-college settings [67–69]. Clearly, rich opportunities exist for more research focusing on online teaching and learning in pre-college education.

Many of the challenges described by students speak to the importance of social interaction and support to enhance learning and increase self-efficacy [57, 66]. Participants talked about the encouragement they received from family and teachers. One student explained that their teacher "... doesn't see us failing and passing as like getting the project done, but more as though we worked to actually do the assignment and we tried our best and put our best effort in. And I like that system, because then it's less of, oh, I actually have to adapt and do something that'll work. So I can get an A. And more I can try and see what works and just work through it." SCCT theory posits environmental support (e.g., support from peer groups, encouragement from family and teachers) to be a precursor of self-efficacy and self-efficacy is hypothesized to have a direct effect on student interest and goals [37]. Students who are unable to understand and learn coursework can feel less efficacious which can decrease interest and future intents. This is a challenge that will need further examination if such experiences are to be taught online.

Connecting to Future Plans: The experience provided by this course afforded students with an opportunity to explore their potential future educational interests and career goals, either in engineering or another field. This approach aligns with SCCT theory, which suggests that vocational and career interests are reinforced by pursuing certain activities (e.g., engineering design), repeated practice, and a sense of capability (self-efficacy) in the tasks [37–39]. For some students, the course confirmed their prior interest and curiosity about engineering. One student noted that, "Ever since I was in middle school, I was just always drawn to math and science. Taking an engineering course obviously, combining both the math and science and the problem-solving for the first time really just solidified what I wanted to do." The experience helped them curtail options within engineering majors as a career path by, ". . . helping [them] narrow down the kind of engineering [they] actually want to do."

Not all students enrolled in the course came predisposed toward engineering. Some expressed a desire to pursue higher education with an engineering or other STEM-related focus because of the skills they had learned throughout this course. Many students mentioned that they had discovered a newfound interest in engineering after taking this course. Examples of students' statements to this effect include, "I feel like we know the main ones, like mechanical, civil. Those are the main ones that everybody knows, but through the [class] it kind of opened us to new categories in what we can do, what we can take, what we learned in the classroom, and maybe find a major we want in college," and "I really liked the first unit because it kind of solidified my view that engineers are everywhere and you can go anywhere with engineering. It kind of helped me feel better about going into engineering."

There were also students who participated in the course and focus groups that did not have an interest in pursuing engineering after high school. Those students still expressed their appreciation for the importance of what the engineering design process had taught them and how it was applicable to their future. For example, one of the students stated, "I can see engineering as a field that people will be interested in doing, and how important it is and how it also connects with the other fields, like I can see myself working better." Approximately 46% (n = 37) students who participated in the focus groups showed interest in pursuing engineering; 19 students indicated preference to pursue careers in non-STEM fields, 8 students suggested interest in pursuing non-engineering STEM careers, and 16 students stated that they were unsure about their future majors. These overall findings for students with an array of career interests are consistent with the findings of a previous study [70] which reported that engineering design experiences increase students' attitude, interest, and understanding with regard to occupations in engineering.

Remote learning initiated by many classrooms during the COVID-19 pandemic revealed additional influences on student higher education and career choices while taking this course. For example, a student noted that the pandemic ". . . made me want to be more of a game designer and producer more because the like the escapism, if I bring the people that is probably in panic because of the virus, just try to make people calm down or just try to not think about too hard." Another student said that the pandemic "really opened [his] eyes to how much engineering is needed in today's times. Everything revolves around it in some way." He elaborated, "I can see items in the house and wonder how if it's not being used, how it can be used for something else, or I can take it apart and use those parts to build something else that would be useful."

5. Implications and Future Work

Emergent themes depict secondary students' experiences related to design activities. These positive and negative experiences are very similar to the experiences that undergraduate engineering students go through in lower division design classes [71–73]. There is an underlying implication in the similarity of the results, which suggests that all novice engineering learners should be exposed to such experiences. Training students on selecting and using appropriate tools and materials for prototyping, communicating for distinct purposes (e.g., sharing, exploring, learning, reporting), and planning for project management are key to the grooming experiences of young minds. Such experiences will doubly benefit those who pursue engineering degrees in two- and four-year institutions because of the early acclimatization.

The e4usa curriculum was developed and piloted in nine schools with the intent to expand engineering literacy "for all" and allow a diverse group of students to explore, build-up, and practice engineering-centric skills. The program has expanded to 51 schools during the 2021–2022 academic year with the program's end goal to reach "all" through a freely available curriculum accessible through the TeachEnginering.com website. Findings from this work highlight the importance of hands-on prototyping and artifact creation experiences in developing students' self-efficacy and interests. Students gained awareness of engineering as a profession and felt better prepared for future education pathways in engineering or non-engineering disciplines. For many, the course solidified their inclination toward engineering pathways or opened new, previously unknown options. For others, the course helped them realize they were "not interested in going into engineering." Such awareness is crucial for students, especially during their formative, secondary school years. All students will be deciding what pathway to travel following high school. It is extremely important that they make informed decisions about their future education pathways and/or career choices. Students that enter four-year programs having made an informed decision improve their retention and graduation rates [65, 74].

The results of this study have broad reaching implications beyond the program context that support and extend previous research. Results demonstrate the interplay between SCCT social cognitive variables (e.g., self-efficacy, interest, outcome expectations, and social support) and career choices. SCCT suggests that repeatedly engaging in an activity, such as engineering design, helps individuals develop an affinity for the activity, feel efficacious, and form goals for sustaining or increasing involvement in the activity. Results showed that design experiences provide an anchor for engineering pathways, indicating the relevance of incorporating engineering teaching and learning in pre-college curricula and developing engineering career interests among pre-college students. The 'E' in STEM often gets lost in pre-college education either as an integrated knowledge area under science standards or as one of many topics under technology education [18, 75]. The encouraging results from this study behooves us to work towards a more judicious pre-college engineering curricula and future standardization in alignment with state and national requirements.

We acknowledge that the e4usa study participants were already enrolled in the course and likely had higher levels of interest in engineering. School district leadership, administrators, teachers, and counselors should consider ways to foster basic engineering literacy and an appreciation of engineering as a valuable pursuit for any student. Teachers and counselors could design and offer curricular, co-curricular, and extra-curricular activities that emphasize not only the technical aspects, but also activities to convey the social aspects of engineering and its value for society. This would map well to the study's participants viewing the course as "learning a skill set that you can take anywhere." This statement is important as it highlights the value students see in such an experience as well as a reason for schools to identify a mechanism for fitting such experiences into an already overcrowded curriculum.

Our future work includes further examination of SCCT's models of interest development, choice, and performance through quantitative measures [76]. Student surveys were administered during the school year and data is being analyzed. The integration of qualitative findings with quantitative data will enable pre-college students' higher education and career selections to be more fully understood, informing engineering education-pathway refinement for future workforce development. We also aim to track e4usa alumni through their higher education programs and/or career choices. We sincerely implore other pre-college programs and researchers to examine connections between exposure to design experiences in secondary schools and persistence in degree programs to better understand whether these interventions are having any impact on student recruitment and retention.

6. Conclusion

Understanding the anchors associated with pre-college students' experiences and their relationships to students' future pathways is an urgent need in the United States as well as internationally. The need for qualified STEM workforce and an overall knowledgeable citizenry is continually becoming a bigger priority. This study explicated a range of student experiences and nuances behind perspectives and choices. Results provided insights into the needs of pre-college engineering curricula, specifically, hands-on design experiences, to increase student recruitment, improve student retention, and help the general public gain a better understanding of what engineering is. We hope this research will impact future motivation and design of pre-college engineering courses, which can become stepping-stones to higher education degree programs for the next generation of the nation's workforce.

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Adam R. Carberry is an associate professor in the Ira A. Fulton Schools of Engineering at Arizona State University. He holds a PhD in Education with a focus on engineering education from Tufts University. His research interests include developing new classroom innovations and assessment techniques (e.g., alternative pedagogies, reflection, and grading systems), and 2) identifying new ways to empirically understand engineering student and educator experiences (e.g., assessments of personal beliefs, expectations, values, risk-taking, intuition, and mindsets).

Medha Dalal is an assistant research professor in the Ira A. Fulton Schools of Engineering at Arizona State University. She holds a PhD in Learning, Literacies and Technologies with a focus on engineering education from Arizona State University. Her research interests span three related areas: (1) democratization of engineering education, (2) ways of thinking, and (3) engineering curiosity among pre-college students.

Olushola Emiola-Owolabi is an eFellow post-doctoral research scholar at Morgan State University. She holds a PhD in Advanced Studies, Leadership, and Policy from Morgan State University. Her research interests are in active learning in engineering classrooms and specializing in qualitative research on engineering teaching and learning – particularly in remote synchronous learning environments.