Exploring the Impact of High School Engineering Exposure on Science Interests (Work in Progress)

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Introduction

A total of 44 states and Washington, D.C. have adopted the Next Generation Science Standards (NGSS) or a variation of these standards that satisfy their state-specific education requirements. By following the NGSS or a similar set of standards, K-12 schools in these areas have established pathways to incorporate engineering into their science coursework [11]. Research on these integrated STEM settings suggests that engineering design activities play an important role in supporting students' science learning [2], [8], [13], [14]. Moreover, the National Academies of Sciences, Engineering, and Medicine named improvement in science achievement as an objective of K-12 engineering education [11]. A less common, though emergent, pathway for schools to offer engineering education is through standalone coursework. As of 2018, only 46% of high schools in the United States offered at least one engineering course [3]. Therefore, likely due to wider implementation, researchers have more extensively studied engineering design activities in science classrooms than independent engineering coursework. This sparse exploration of standalone engineering coursework, coupled with the promising findings from integrated STEM education and the theorized importance of engineering education in science learning, motivated us to investigate the extent to which engineering design curriculum impacts high school students' interest in learning more about science.

Context

This work-in-progress study is a part of a National Science Foundation-funded project that investigates the implementation of Engineering For Us All (e4usa), a yearlong high school course that introduces students across the United States to engineering design principles. By situating engineering design problems in local and global contexts relevant to students' interests, this course aims to appeal to all students, not just those interested in pursuing a post-secondary engineering pathway. Additionally, to eliminate barriers to entry, the only prerequisite that e4usa requires is Algebra I, and teachers are not required to have backgrounds in engineering. To prepare the teachers to implement the e4usa curriculum, e4usa provides five weeks of professional development during the summer. The e4usa curriculum includes four main student objectives: discover engineering, understand the intersection of engineering and society, gain professional skills, and navigate the engineering design process. For the 2020-2021 school year, e4usa's first year of full implementation, there were 36 partner high schools across 12 states, Washington, D.C., and the U.S. Virgin Islands.

Literature Review

In this section, we review past scholarship on secondary engineering education, specifically exploring literature related to engineering design activities in middle school and high school science classrooms. In addition, we discuss the ways in which researchers have described engineering knowledge and its connections to science knowledge.

Engineering Design in Secondary-Level Integrated STEM Settings

Integrated STEM education is defined as "the teaching and learning of the content and practices of disciplinary knowledge which include science and/or mathematics through the integration of the practices of engineering and engineering design of relevant technologies" [4, pp. 23-24]. The impacts of formal integrated STEM education on middle school and high school students' learning have been well-studied over the past decade, and through these explorations, engineering design activities have been found to potentially have a positive effect on secondary students' science learning. As Wendell and Rogers noted, "Engineering design practices complement the essential features of science learning, such as asking scientifically oriented questions, giving priority to evidence, formulating explanations from evidence, connecting explanations to scientific knowledge, and communicating and justifying explanations" [8, p. 516]. This claim is well-supported by empirical studies in secondary integrated STEM settings. For instance, Apedoe et al. found that the implementation of a heating/cooling engineering design project into high school chemistry courses increased students' understanding of chemical reactions [15]. Beyond the understanding of science material, there is also evidence that indicates engineering design activities in secondary-level science classrooms increase students' excitement about science, their confidence in their science abilities, and the effort they put into science [2], [13]. Given the promising nature of these findings for integrated STEM settings, we suggest that it is important to study the impact of standalone engineering design coursework on high school students' relationship with science, namely their interest in learning more about science.

The Interconnectedness Between Engineering and Science Knowledge

In recent years, there have been efforts to understand the relationship between science knowledge and engineering knowledge. Specifically, Antik-Meyer and Brown developed a conceptual framework on the nature of engineering knowledge (NOEK), in which they described engineering as interdisciplinary due to its interrelated and co-dependent relationship with science and technology [1]. Furthermore, Pleasants and Olson identified, "How do engineering and science influence one another?" as a question that K-12 students should explore as they learn about the nature of engineering [6]. This conceptualized emphasis on the interconnectedness between engineering and science further motivates us to gain a better understanding of how engineering design coursework alters students' view of science.

Research Question

This study aims to explore the impact of high school students' exposure to engineering design curriculum on their science interests. As such, we address the following research question: How, if at all, does high school students' exposure to engineering design curriculum impact their interest in learning more about science?

Methodology

This study utilized part of e4usa's Fall 2020 student focus group data. To construct the Fall 2020 student focus group protocol, the research team expanded upon the 2019-2020 protocol, which focused on the evaluation e4usa. As part of this expansion, for the purpose of this work-in-progress study, the research team developed the science interest item, "In what ways has your interest in your science courses been impacted as a result of this course, if it has at all?"

In December 2020, two e4usa external program evaluators conducted six semi-structured student focus groups across five high schools. Each focus group lasted approximately 30-minutes and took place through the video conferencing tool, Zoom. A focus group method was considered appropriate for collecting data for this work-in-progress study since we aim to gather baseline information about the impact of exposure to engineering design curriculum on students' interest in science [10]. For four of the high schools (a total of five focus groups), the Zoom audio recordings were transcribed verbatim and, for the sixth focus group (School 2), the external evaluator who was not the main interviewer took detailed notes of the students' responses during the focus group.

Following the qualitative coding methods recommended by Saldaña [7], the lead author utilized a two-cycle coding process to analyze the student focus group transcriptions and notes. For the first cycle, an in-vivo coding method was applied in order to prioritize the students' voices [7]. Then, for the second cycle, the lead author abstracted these codes into themes and categorized the quotes based on the emergent themes. The lead author's analysis was discussed and agreed upon by the other two authors of this paper to ensure its validity [14].

Participants

No demographic information was collected about the focus group participants besides their gender identity. Given the options female, male, transgender female, transgender male, gender variant/non-conforming, and other (please list), the teachers at each of the five schools identified all of their students as either female or male. Table 1 includes this information, school-level demographic information [12], and the e4usa teachers' teaching experience before their e4usa curriculum implementation during the 2020-2021 school year.

Table 1: Participant gender identity, school-level demographic information, teacher context

	State	School Context	Teacher Context	Female	Male
School 1	AZ	Urban, public charter, majority Latine enrollment (80%), 94% of students qualify for free or reduced-cost school meals	Engineering, physical sciences	9	9
School 2	NM	Rural, public, majority Indigenous enrollment (100%), 100% of students qualify for free school meals	Physical sciences, robotics	7	5
School 3	VA	Rural, public, majority white enrollment (99%), 59% of students qualify for free or reduced-cost school meals	Engineering, technology	0	3
School 4	NY	Urban, independent, all-girls, majority white enrollment (53%)	Algebra, engineering, physical sciences	10	0
School 5	TX	Urban, independent, all-girls, majority white enrollment (55%)	Engineering, physical sciences	10	0

Preliminary Results

Out of the 53 students who participated in the six focus groups, 15 students discussed their interest in science. One of the students (a male student from School 1) indicated that his interest in science did not change over the first semester of e4usa, and 14 students indicated that their interest in science increased as a result of being exposed to the e4usa curriculum. Of these 14 students, three students (two male students from School 3 and one female student from School 2) did not explain how or why their interest in science increased. For the 11 students who provided an explanation as to how their interest in science increased because of e4usa, three themes emerged according to the analysis of students' responses, which will be presented in this section. Since the researchers did not have the opportunity to select pseudonyms alongside the participants, to avoid misrepresenting them, the lead author decided to describe all participants in terms of gender identity and school [10].

Theme 1: e4usa led students to see science as a more interesting subject (one female and one male student from School 2, two female students from School 4).

> *I liked science before this class. . . learning about animals. . . but engineering came in and made it better. Now I have a class I look forward to every day.* (Male Student 1, School 2)
>
> *I greatly struggled in biology and chemistry and that kind of like made my interest in science go downhill. But then, when I came to engineering, I was like there's so much more to science than chemistry and biology. Like my eyes were open to this whole new world. . .* (Female Student 1, School 4)

Theme 2: The activities in e4usa piqued students' interest in how physical systems work (four female students from School 5).

> *I think it'd really be helpful rather than just kind of building and like learning the engineering design process and doing the engineering design process, learning about what like physics and why our builds work the way that they do and how and actually how they're working.* (Female Student 1, School 5)
>
> *Definitely incorporating the science of why this happened. Like taking the water filter example we did, like sort of, what made the pH curve like bring it back to more than normal and just what happened there. I kind of want to figure out the science of that in future courses. . .* (Female Student 2, School 5).

For this theme, the quotes presented above are students' responses to a question in the student focus group protocol related to how e4usa could improve for future implementations, not responses to the science interest item. Additionally, all of the data categorized under Theme 2 corresponds to students who attend School 5. At School 5, the e4usa curriculum was blended with conceptual physics curriculum, which may have impacted the respondents' perspectives about e4usa and their interest in learning more about science.

Theme 3: The e4usa teacher's implementation of the curriculum fostered students' interest in science (two female students and one male student from School 1).

> *More because I feel like [teacher name] is just good at teaching 'cause in eighth grade and like other grades, I didn't like [science] just because of the way it was taught. Like it wasn't really taught. We just like saw a screen and like that. But with [teacher name], she actually explains it well, and, yes, I feel like my interest has gone up.* (Female Student 1, School 1)
>
> *Other teachers would like just like show you the things, but they wouldn't actually engage you into it. And because [inaudible] getting us engaged into it, I feel like my interest has grown.* (Female Student 2, School 1)

Discussion

The preliminary findings of this work-in-progress study well support existing K-12 integrated STEM and engineering education scholarship. Under Theme 1, students discussed how the e4usa course led them to view science as a more exciting subject and expanded their ideas about what science entails as a discipline, which aligns with the nature of engineering knowledge (NOEK) framework. Interdisciplinarity is a dimension of NOEK because of the interrelated and co-dependent relationship between engineering, science, and technology [1]. This finding also suggests that students considered how engineering and science influence one another, which Pleasants and Olson posed as an idea that students should explore as they learn about engineering [6].

Theme 2, e4usa activities piqued students' interest in how physical systems work, also exemplifies students' consideration of how engineering, particularly engineering design, and science influence one another. Furthermore, this finding provides empirical evidence to support Wendell and Rogers' claim that engineering design activities enhance aspects of science learning by prompting students to formulate explanations based on evidence and to connect explanations to scientific knowledge [8]. However, as noted in the Preliminary Results, the student outcomes associated with Theme 2 may have been influenced by the teacher's decision to integrate conceptual physics lessons into the e4usa curriculum.

The students whose responses were categorized under Theme 3 expressed that their teacher's implementation of the e4usa curriculum caused their interest in science to grow, which demonstrates that, in addition to the engineering design curriculum itself, a teacher's implementation of the curriculum is also important for increasing students' science interest. In Hill et al.'s meta-analysis of 89 professional learning programs for STEM teachers, the researchers found that programs that focused on training teachers to use curriculum materials and strengthening teachers' content knowledge, pedagogical content knowledge, and knowledge of student learning were associated with better achievement outcomes when compared to programs that did not emphasize these goals [5]. Our findings suggest that e4usa's professional learning program potentially plays an important role in guiding teachers to implement the curriculum in a way that strengthens students' interest outcomes, which should be further explored in future work.

Conclusion

This work-in-progress paper provides insight into the impact that standalone engineering design curriculum has on high school students' interest in learning more about science. We have provided a preliminary exploration into the themes relating to how exposure to engineering design curriculum impacts students' interest in learning more about science, as reported by e4usa student participants. The results yielded from our exploration suggest that more work should be done to gain a deeper understanding of the influence e4usa (a standalone engineering design course) has on students' science interests. More broadly, we suggest that future K-12 engineering design impact studies should focus on how the specific activities embedded in engineering design courses influence students' interest in learning more about science and the role engineering design teachers play in increasing students' interest in science.

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