The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #41525

Board 167: Pre-College Engineering: Perspectives of Engineering Faculty (Work in Progress)

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Introduction

Despite a growing emphasis on engineering in grades K-12, persistently high dropout rates plague undergraduate engineering programs [1],[2]. Prior studies indicate that engineering activities have the potential to increase interest in engineering pathways [3] or develop an engineering identity [4]. Less clear is whether pre-college engineering instruction also contributes to students' success in engineering career pathways by adequately preparing students for undergraduate engineering. One concern is that K-12 engineering lessons "may mislead or under prepare [students] by providing activities that they enjoy but which have little relation to engineering practice" [5, p. 11]. For example, popular K-12 engineering activities like designing a tower to hold weight or building a roller coaster to meet criteria are often repeated across elementary, middle, and high school grades without clear learning progressions [5]. While engaging, such building projects generally promote a tinkering approach to develop a working prototype [6], [7], [8] that does not reflect the work of expert engineers [9], [10]. To support the development of more authentic engineering learning outcomes and goals in K-12 settings, previous studies have engaged engineering experts, such as professional engineers [11] and philosophers of engineering [12]. This study builds on that work by exploring the perspectives of engineering university faculty—individuals who are aware of the strengths and weaknesses in the existing population of engineering students and what is required for their preparation [13].

This work in progress study examines the perspectives of those who directly prepare engineers and seeks their perception of what is important for all students, not just future engineers, to learn in the middle school grades. Employing a convergent mixed methods approach, the quantitative component aimed to establish the priority that faculty members place on different engineering topics for their integration into the K-12 curriculum. The qualitative component provided insight into the reasons behind faculty priorities to understand how K-12 instruction can better prepare incoming engineering students. Integration of the two strands allows for triangulation through comparing for convergence and divergence [14] [15]. The study is guided by the following research questions based on engineering faculty perspectives:

1. What are the strengths and weaknesses of current undergraduate engineering students?
2. What are the most important engineering-related topics for high school instruction?
3. What are faculty perspectives on current middle school engineering instruction practices?
4. How can middle and high school programs best prepare future engineering students?

Theoretical Framework

This study is guided by the work of Schwab [16], who emphasized the importance of four perspectives in curriculum development. These include subject matter experts who understand the discipline, educational psychologists who understand learning and developmental appropriateness, educators who understand teaching environments, and those from the milieu who understand the workplace and greater context. This research brings in the subject matter experts who are knowledgeable in engineering content, research, and education of future engineers [13]. This perspective can play a pivotal role in ensuring that K-12 engineering education efforts are grounded in rigorous and relevant content to ensure that students aspiring to careers in engineering are thoroughly prepared and fosters an accurate understanding of engineering for all students.

Methods

To investigate faculty perspectives, this study used a convergent mixed methods approach through an online survey distributed to university faculty members with experience teaching undergraduate engineering. The survey questions were developed through an iterative process of piloting and feedback with a group of five engineering faculty members. Appendix A outlines how survey questions were connected to each research question. Since the survey contained quantitative and qualitative data, each was analyzed separately using different approaches and then compared for convergence or divergence [14] [15].

Data Collection and Analysis

Upon refining the survey based on pilot feedback, it was distributed to a purposive sample of engineering faculty using an online survey platform. Eligible participants included faculty in an engineering department with at least one year of experience teaching undergraduate engineering students. Participant recruitment was via an email sent between August – October 2023 containing a brief study description and a link to participate, and participants were informed that their responses were anonymous, confidential, and voluntary. Researchers targeted faculty members from various geographic locations within the United States by emailing ASEE program chairs and engineering departments across several universities. Based on the participants' reported areas of expertise (N=160), 41% of faculty were from mechanical, civil, or environmental engineering programs (Appendix B). Most participants were faculty members at public institutions (84%); 67% were tenure-track, and 23% were in an instructional or clinical role. Respondents were 61% male and predominately White/Caucasian (73%).

Results

This work-in-progress paper presents preliminary results for RQ2, which includes a ranking task where participants were asked to consider the importance of various engineering topics for a high school curriculum. Respondents were asked to identify the engineering topics as "essential," "nice to have," or "not important" (given a score of 3, 2, and 1, respectively) for two groups of students: high school students intending to major in engineering and all high school students. The selected topics were derived from the FPEL [5], which defines K-12 engineering learning as including habits of mind, engineering practices, and engineering knowledge (Appendix C).

The results of the ranking task are shown in Figure 1. Participants ranked FPEL topics in the same order of priority for both groups. Math was at the top of the list, with a mean of 2.96 out of 3 for future engineering students and 2.64 for all high school students. 96% of respondents viewed math as "essential" for future engineering students, and 63% viewed math as "essential" for all students. Another top priority was understanding the natural sciences, with a mean score of 2.92 out of 3 for future engineering students and 2.61 for all students. None of the participants rated math or science as "not important" for either group.

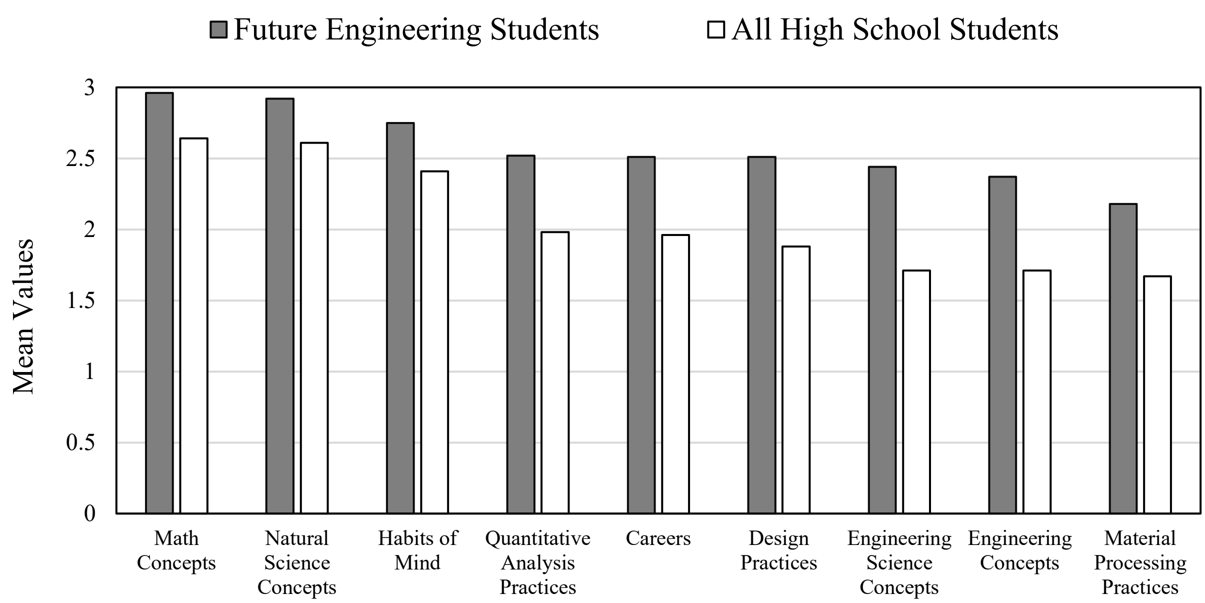

Figure 1. Mean Values for FPEL Topics

For future engineering students, all topics had a mean value above 2.18 out of 3. However, in ratings for all students, 6 out of 10 topics received a mean score below 2 (Figure 2). For engineering design practices, 25% rated engineering design practices as "not important" for all students, while only 10% rated design practices as "essential" for future engineers.

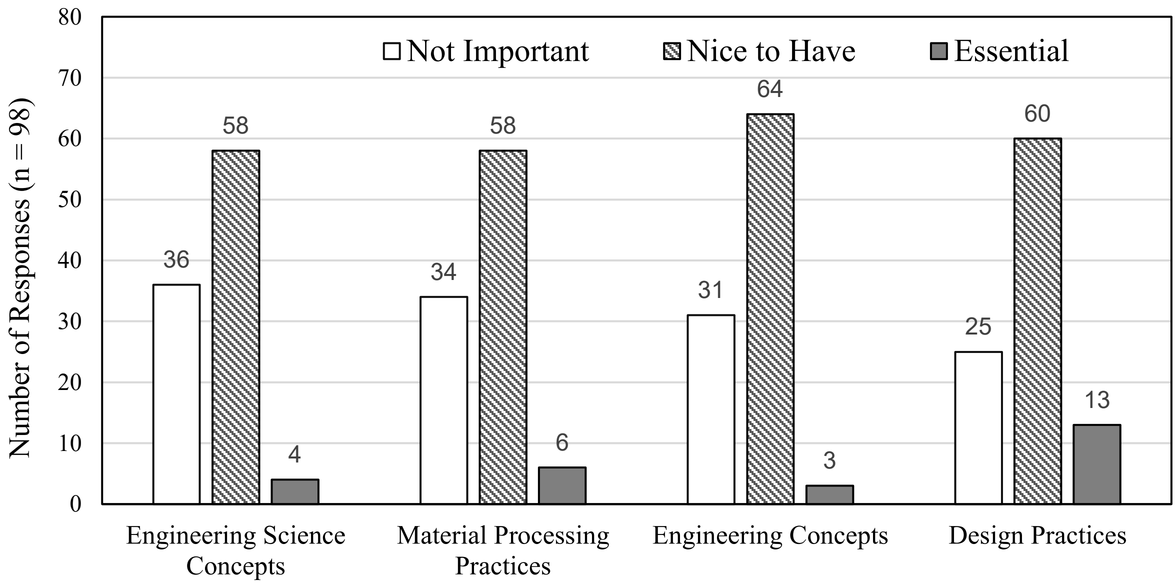

Figure 2. Lowest-rated FPEL Topics for All High School Students.

Participants had the opportunity to leave comments about their choices following the ranking task. Nearly half (47%) indicated their rankings were influenced by the belief that "all students should have the basic building blocks to become engineering students" (P137). The most essential topics were identified as math and science (51%). One faculty participant stated, "If students have a good foundation in math and science, then it is relatively easy for them to succeed in engineering and computer science" (P41). Another described how "they don't have to come to college knowing engineering concepts, but they need to have the math/science foundation" (P78). However, faculty participants appeared split on whether engineering-specific topics should be taught at the high school level. While 16% advocated for the importance of topics like design thinking or engineering mechanics in high school, 12% argued that "the more engineering things can wait for college" (P18).

Discussion

These rankings indicate the prioritization of engineering-related topics from the perspective of engineering faculty who prepare future professional engineers. Engineering faculty assessments of the FPEL topics show broad agreement on their importance for *future engineering* students, with all topics averaging scores above 2.18 out of 3, indicating a consensus on their foundational value for this population. However, not all topics were deemed equally critical for *all* students. Significantly, engineering faculty do not prioritize the teaching of design practices in K-12, preferring instead that students concentrate on developing a strong foundation in math and natural sciences. However, these topics are inconsistent with the prevailing focus of K-12 engineering education that centers around developing design practices, often through the development of a physical prototype to meet criteria [17]-[25].

Importantly, the topics most valued by faculty, such as math and science, should not be taken as a recommendation for promoting this learning within an engineering context. Emerging research has shown that engineering design activities rarely make explicit use of science concepts, which indicates that time to learn science is being reduced when engineering is sharing space in the science curriculum [26], [27]. Students also struggle to identify and incorporate relevant scientific ideas in design activities [28], [29]. Therefore, science teachers are increasingly including engineering activities that promote design practices while reducing time spent learning science [30]. In developing engineering learning goals, faculty recommendations should be taken into consideration alongside research on developmental appropriateness and effectiveness of integrations.

The initial findings illustrate a gap between the engineering subjects that faculty believe are essential for students and the focus of current pre-college engineering programs. The next steps include analyzing the remaining open-ended survey responses to further analyze faculty views and how they align with quantitative data. These perspectives provide a starting point for developing authentic learning goals for K-12 students.

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Appendix A: Survey Questions

Research Question		Survey Questions Included in Analysis
1	What are the strengths and weaknesses of current undergraduate engineering students?	*Qualitative*: (Q1) Which skills or concepts do students typically excel at in your undergraduate classes? (Q2) Which skills or concepts do students typically struggle with in your undergraduate classes?
2	What do engineering faculty consider to be the most important engineering-related topics for high school instruction?	*Quantitative Ranking*: (Q3) Consider the engineering-related concepts and skills listed below. How important is each topic for inclusion in a high school curriculum? Consider learning goals for preparing future engineering students and preparing all high school students to be informed citizens. *Qualitative:* (Q4) Provide any comments on your ranking decisions. (Q5) What skills and/or concepts do you believe are most essential for high school students who intend to study engineering in your department?
3	What are faculty perspectives on current middle school engineering instruction practices?	*Qualitative:* Here is a common engineering activity for middle school students [description of popular paper roller coaster design activity]. Consider students who want to become engineers. (Q6) Which aspects, if any, of this rollercoaster activity would best prepare students for your undergraduate program? (Q7) What recommendations do you have to improve the engineering-related learning outcomes of this rollercoaster activity?

Appendix B: Faculty Field of Expertise (N=160)

Field of Study	n	%
Mechanical Engineering	21	22
Civil & Environmental Engineering	18	19
Biomedical Engineering	9	10
Computer Science & Engineering	9	10
Chemical Engineering	7	8
Engineering Education	7	8
Biological & Agricultural Engineering	5	5
Electrical Engineering	5	5
Industrial & Systems Engineering	4	4
Aerospace Engineering	3	3
Materials Science & Engineering	2	2
Other	2	2
Nuclear Engineering	1	1
Engineering Technology	1	1
Ocean Engineering	0	0
Petroleum Engineering	0	0

Appendix C: FPEL Topics Included in Survey to Faculty

Engineering Topic from FPEL	Topic Included in Ranking Question
Habits of Mind	
Habits of Mind	**Habits of Mind:** Approach to engineering problems (e.g. systems thinking)
Engineering Practices	
Material Processing Practices	**Material Processing Practices:** Convert materials into products through the use of tools, machines, and processes
Engineering Design Practices	**Engineering Design Practices:** Define engineering problems, generate and evaluate solutions, build and test prototypes, and optimize a solution
Quantitative Analysis Practices	**Quantitative Analysis Practices:** Use mathematical models, computations, and simulations for predictive decision-making
Professionalism	**Careers**: Engineering career pathways
Engineering Knowledge	
Engineering Sciences	**Natural Science Concepts:** Principles and laws of the natural world (e.g., physics, chemistry) **Engineering Science Concepts:** Science concepts primarily used by engineers (e.g., statics, thermodynamics)
Engineering Mathematics	**Math Concepts:** Mathematical techniques (e.g., algebra, geometry)
Engineering Technical Applications	**Engineering Concepts:** Engineering principles (e.g., mechanical design, electronics)