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Examining Hard and Soft Skill Prioritization in High-School Engineering Education

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Abstract

In high school engineering education teachers face a significant pedagogical load, trying to integrate different dimensions of 'hard' and 'soft' skills alongside codified educational standards in their teaching. Artificial intelligence systems may have promise to relieve some load for teachers, but care must be taken to design these systems to support, not hinder, teachers' own pedagogical priorities. Towards designing an AI system for engineering education classrooms, we conducted a semi-structured interview study (N = 5) with high school engineering teachers to elicit their pedagogical practices around the engineering design process (EDP). Here we investigate how teachers prioritize 'hard' and 'soft' skills for their students in engineering design projects and explore the implications of supporting these skills via an intelligent system.

Introduction

Engineering education has become commonplace in K-12 education, even becoming a national standard [1,4]. The Engineering Design Process (EDP) is often used as a general theoretical framework to teach engineering classes, particularly at the K-12 level [10,11]. At the high-school level, students in engineering courses should learn both 'soft' and 'hard' skills to prepare them for successful long-term employment, including teamwork, communication, and problem-solving [5,6,7,18]. This leads to a significant cognitive and pedagogical load for teachers implementing the EDP in their classrooms. Providing teachers with support to scaffold asynchronous, team-based design challenges may alleviate some of the challenges of teaching high school engineering [10,14,16]. The integration of Artificial Intelligence (AI) into engineering classroom technology is a promising avenue to enhance pedagogy; however, designing effective intelligent systems requires deep understanding of high school engineering educators' pedagogical practices.

In this paper, we focus on understanding teachers' beliefs regarding student learning priorities in engineering education at the high school level. We inductively categorize those skills into hard and soft skills and explore the implications for integrating support for these skills into an intelligent system.

Related Work

The EDP is a cornerstone of engineering teaching and practice used as a framework for engineering curricula in K-12 education [11]. However, high school engineering experiences are constrained by classroom environments and often do not reflect the true multidisciplinary nature of engineering problems [10]. Prior research has shown that other factors such as practical constraints (e.g., administrative requirements, state standards, student assessments, time) [1,8], and teachers' understanding of engineering [9,15], motivations, and personal priorities [13] can shape how the EDP is taught.

In order to further support teachers in balancing these different dimensions of their pedagogical practice, a better understanding of classroom priorities is needed. As Garner and Gabitova state, the emergence of the STEM education movement emphasizes that "solutions to real-world problems are rarely found within one discipline perspective or body of knowledge" [12]. More specifically, Harris and Rogers show that "soft skills are an integral part of careers in technology and engineering" [6]. There are synergies between hard and soft skills; for example, critical thinking, a paramount competence in engineering, has been predicted positively by social and emotional skills [2].

In this paper, we define hard skills as technical content related to the EDP, tool usage, and/or mathematical or scientific principles. EDP applications include thinking critically about a problem, analyzing data, designing and evaluating solutions, and justifying decisions. We define soft skills as abilities that prepare students for different professional and collegiate careers including abilities such as learning strategies, understanding societal impacts of engineering, team and time management, empathy, creativity, and communication skills.

Artificial Intelligence systems may be able to support teachers in certain aspects of this open-ended learning environment [14,16] by empowering them to fully enact their pedagogical goals with fewer resources. However, to inform the design of technology for the engineering classroom, we must first understand teachers' values in terms of soft and hard skills taught in practice.

Methods

Recruitment and Participants

Under approval of our institutional review board, we recruited current full-time high-school level (i.e. grades 9-12) teachers who have been teaching engineering through design challenges as a part of their classroom curriculum for at least one academic year. Specifically, we invited teachers who have not previously participated in our institution's professional development programs around the EDP. Email invitations were sent through our database of school and teacher contacts with a link to an Eligibility and Interest survey containing questions about teachers' educational and professional background, demographic background, and contact information to help us select a sample with a broad range of experience and expertise.

In total, nine teachers completed the survey, from which five participants were recruited for inclusion in the study. This group represents four school districts in the metropolitan area of a city in the Southeastern U.S. (See Table 1). Their high-school engineering teaching experience ranged from five to 24 years (mean = 12.8, median = 8). Participants have all previously taught the *Foundations of Engineering and Technology*, the first course in the high school engineering pathway, and *Engineering Concepts* (second course). Additionally, three of our participants have taught the capstone *Engineering Applications* course. Participants' (referred to as P1-P5) demographic data is shown in Table 1.

Data Collection

Semi-structured interviews lasted two hours each and were conducted between April 2022 and July 2022, either in-person or virtually according to the participants' preference. Before the interview, each teacher was asked to submit teaching materials consisting of two unit maps, lesson plans, or the closest equivalent used to teach a design challenge centered around the EDP, one that they felt was taught successfully and one they would like to improve upon.

Each interview was arranged in four sections. The first section focused on general questions about the participant's experience teaching engineering and the EDP. The second section consisted of a walkthrough of the first unit map for the design challenge that the participant considered most successfully taught, prompting them for examples and asking them to map the different steps and substeps of the EDP to their teaching plan. During the third section, we reviewed the second unit map for the design challenge that the participant considered less successfully taught or would like to improve on, focusing on examples and details about challenges they and their students encountered. In the fourth section, we inquired about their process for producing new teaching materials and design challenges, including their planned classroom practices and anticipated challenges. Participants were compensated for their participation.

Data Analysis

We qualitatively analyzed video recordings of the interviews [3]. We first identified all video excerpts in which teachers mentioned a priority in their teaching, related either to their values and/or responsibilities and/or to their students' educational experiences. This resulted in 467 total excerpts. In this analysis we focus on all mentions related to students, and more specifically, skills, resulting in 231 coded segments. We used inductive coding [3] to classify each skill into 29 skill categories, some of which were reorganized into subskills (see Figure 2), resulting in 319 total skills mentions. Another round of coding further identified each excerpt as statements related to *hard skills* (n = 158), statements related to *soft skills* (n = 161), or statements combining both (n = 34). Both categories include subcategories. For example, *hard skills* includes subcategories such as *applying the EDP and steps, theory and foundational concepts,* and *tools*, while *soft skills* includes subcategories such as *learning strategies, team management,* and *bigger picture knowledge*.

Findings

Our findings show that teachers value both hard and soft skills, but their perceived importance varied across participants. In terms of hard skills, *Applying the EDP* was mentioned most times (n = 77) (Figure 1). For example, P1 reported that he tells students that they will apply the EDP *"in every single thing we do in my class for the next four years.*" More specifically, at the sub-skill level, all five participants unanimously mentioned the importance of applying all EDP steps for classroom projects (n = 22), and of documentation of the EDP steps (n = 19). In explaining the importance of documenting all ideas to her students, P4 encourages the *"cocktail-napkin philosophy [...]* *mimicks a student quickly sketching an idea* *then just document that in the notebook, throw all that in the notebook.*" This was followed by *critical thinking*, mentioned 25 times, by four participants (P2-P5).

In contrast, there were no soft skills unanimously valued by all participants. However, *seeing the bigger picture*, including being able to translate abstract knowledge and ideas into concrete solutions in context (n = 29) and understanding the interdisciplinary nature of engineering work (n = 14), was mentioned 43 times by four participants, as shown in Figure 2. For example, P2 explained, "*I want them to come full circle, [..] you are here because you are going to be an agent of change, to change society in a positive way through technology.*" This was followed by *team* and *time management*, each mentioned 16 times.

Overall, across all five participants, we found that hard and soft skills were discussed in almost equal numbers. We found a total of eight hard skills, including 18 sub-skills, from 158 value statements. In contrast, there were a total of 13 soft skills, including 9 sub-skills, totaling 161 mentions. However, we observe a diversity of perspectives in how different teachers value these skills with more than 60% of P1 and P5's statements focusing on hard skills compared to only 30% for P2 (Figure 3). Interestingly, we note that, P1 and P5 have extensive teaching experience (24 and 21 years, respectively) and no engineering industry experience, while P2 is an engineer by trade and only recently became a teacher. While we cannot generalize based on our limited dataset here, this potential correlation warrants future study.

Discussion

While state educational standards and curricula may appear somewhat uniform, in practice, engineering classrooms look different. Our findings show that teachers emphasize and value soft and hard skill dimensions at different levels, and more broadly, that there are differences in how teachers talk about their priorities in teaching and as related to student outcomes. This may be due to different factors, including teachers' educational and professional backgrounds and diverse students' needs. We argue that adaptation is a positive attribute, as different students and communities need different support. In open-ended, multidisciplinary learning environments, standardizing the assessment of skills such as empathy may lead to serious problems such as stress and anxiety [17]. Additionally, while we categorize skills as soft and hard for discussion, we do not prescribe an optimal balance of these skills in practice. Blending these skills in the context of projects can provide learners with a more well-rounded educational experience [7].

As we move to design technology mediation for these environments, we suggest that AI systems could help teachers provide students with more support in fostering some of these skills. For example, documentation and/or team management could be scaffolded through pedagogical tools with guidance and feedback features to focus on elements of good engineering practice. We recommend that AI and educational technology designers reflect on different teachers' priorities and perceptions of skills in engineering education, as well as the careful integration of both hard and soft skills training in the design of classroom systems, and provide teacher-driven flexibility.

Limitations and Future Work

This preliminary study included only five teachers, all teaching in the same state and following the same state standards. Therefore, we cannot generalize our findings to differences that may be visible in other states or regions in the U.S. Future work should consider teachers with variations in educational, professional, and engineering-specific backgrounds, as well as other mediating factors (e.g., school and district mandates, student motivations). While we focus on a specific perspective in this paper, our future work aims at taking a more situated approach by examining the intersections of different factors.

Conclusion

We present an analysis of skills that surfaced during semi-structured interviews with high-school engineering teachers. Our analysis elicited a variety of priorities in terms of both hard skills–those that are typically considered to be core skills in engineering education–and more generalizable soft skills. This analysis is in service of ongoing design work on an artificial intelligence system that can support teacher practice. Similar to the power held by standards and curriculum developers in shaping the educational environment, AI agents in high-school education will introduce an additional layer to the existing power structure. Therefore it is crucial that, as AI and curriculum designers, we acknowledge our responsibility and deeply reflect on the power structures and value judgments when designing technology interventions in the classroom, and their broader impacts.

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ID	Gender*	Demographic Background	High-school engineering teaching experience (in years)	Highest Degree Achieved	Industry Experience in Engineering**
P1	M	White	24	Ph.D. in Education	No
P2	M	Black or African American	5	M.B.A.	Yes
P3	W	Black or African American	8	Specialist Degree	No
P4	W	White	6	Ph.D.	No
P5	W	White	21	Specialist Degree	No

*Table 1: Participant Demographics. *We used an open-ended question to ask participants what gender they identified as; we received two response types: "man" (M) and "woman" (W). **We used an open-ended question to ask participants about their industry experience related to engineering, we received answers with different levels of detail and categorized those answers as "yes" and "no."*

Skill	Definition	P1	P2	P3	P4	P5	# of Mentions
Applying the EDP and Steps	**Statements related to applying the EDP or its steps**						**77**
General	Statements related to applying the EDP in general	■	■	■	■	■	22
All steps before building	Statements related to applying all the EDP steps before building (e.g., identifying the problem, research, brainstorm)				■		1
Identifying the problem	Statements related to the identifying the problem step		■	■	■		4
Research	Statements related to the research step	■		■	■		7
Customer needs	Statements related to the customer needs step		■				1
Understanding requirements	Statements related to understanding requirements step		■				1
Design	Statements related to the design step	■		■			3
Lo-fi prototypes	Statements related to the lo-fidelity prototype step	■					2
Brainstorm	Statements related to the brainstorm step	■			■		2
Building plans	Statements related to the building plans step			■			1
Sketching	Statements related to the sketching step				■	■	4
Evaluation	Statements related to the evaluation step	■				■	3
Documentation	Statements related to documenting the EDP and its steps	■	■	■	■	■	19
Iteration	Statements related to iterating through different EDP steps	■	■			■	7
Process thinking	Statements about thinking in the frame of the EDP	■			■	■	9
Critical thinking	Statements about thinking critically about the problem		■	■	■	■	25
Problem solving	Statements about mapping out a set of solutions to the problem			■	■	■	6
Theory + Foundational concepts	Statements about domain knowledge, theories and concepts		■	■		■	9
Math and science	Statements about mathematical and scientific skills		■		■		8
Tools	**Statements related to power tools and safety skills**						**12**
Power tools	Statements related to learning how to use power tools	■		■	■		7
Safety	Statement related to understanding/abiding by safety guidelines	■		■	■		5
Software	**Statements related to software skills**						**12**
CS	Statements related to Computer Science skills (e.g., programming)			■			1
Computer modeling (2D/3D)	Statements related to computer modeling skills (e.g., AutoCad, OnShape)			■	■	■	11
Total							158

Figure 1: Breakdown of hard skills including definitions, participant mentions, and total number of mentions per skill and sub-skill.

Skill	Definition	P1	P2	P3	P4	P5	# of Mentions
Learning Strategies	Statements related to learning strategies						28
Self-directed learning	Statements related to self-directed learning skills	■		■	■	■	9
Long-term learning	Statements related to long-term learning skills		■	■	■		5
Social emotional learning	Statements related to social/emotional learning skills			■		■	2
Unlearning	Statements related to unlearning some habits or strategies				■		2
Collaboration	Statements related to learning from collaboration		■	■	■		5
Competition	Statements related to learning from competition			■			5
Seeing the bigger picture	Statements about understanding bigger picture aspects of engineering						43
Connecting abstract to concrete	Statements about connecting abstract concepts to concrete applications (e.g., career preparation, societal impact)		■	■	■	■	29
Interdisciplinarity	Statements about the interdisciplinary nature of engineering		■	■	■		14
Team management	Statements about team management skills	■	■	■	■		16
Responsibility	Statements about taking responsibility/being accountable		■		■	■	8
Time management	Statements about time management skills	■		■	■	■	16
Marketing	Statements about marketing solutions/artifacts	■	■	■			6
Communication	Statements about communication skills/articulation	■	■	■	■		12
Writing	Statements about writing skills	■	■	■	■		4
Empathy	Statements about empathy skills	■	■				6
Understanding Feedback	Statements about understanding and incorporating feedback				■		3
Creativity	Statements about creativity/generating novel ideas	■			■	■	13
Ethics	Statements about work ethic				■	■	2
Sense of efficacy	Statements about developing a sense of efficacy (e.g., students knowing their limits, feeling accomplished)		■	■	■	■	6
Information access	Statements about information access skills		■				2
Total							161

Figure 2: Breakdown of soft skills, including definitions, participant mentions, and total number of mentions per skill and sub-skill.

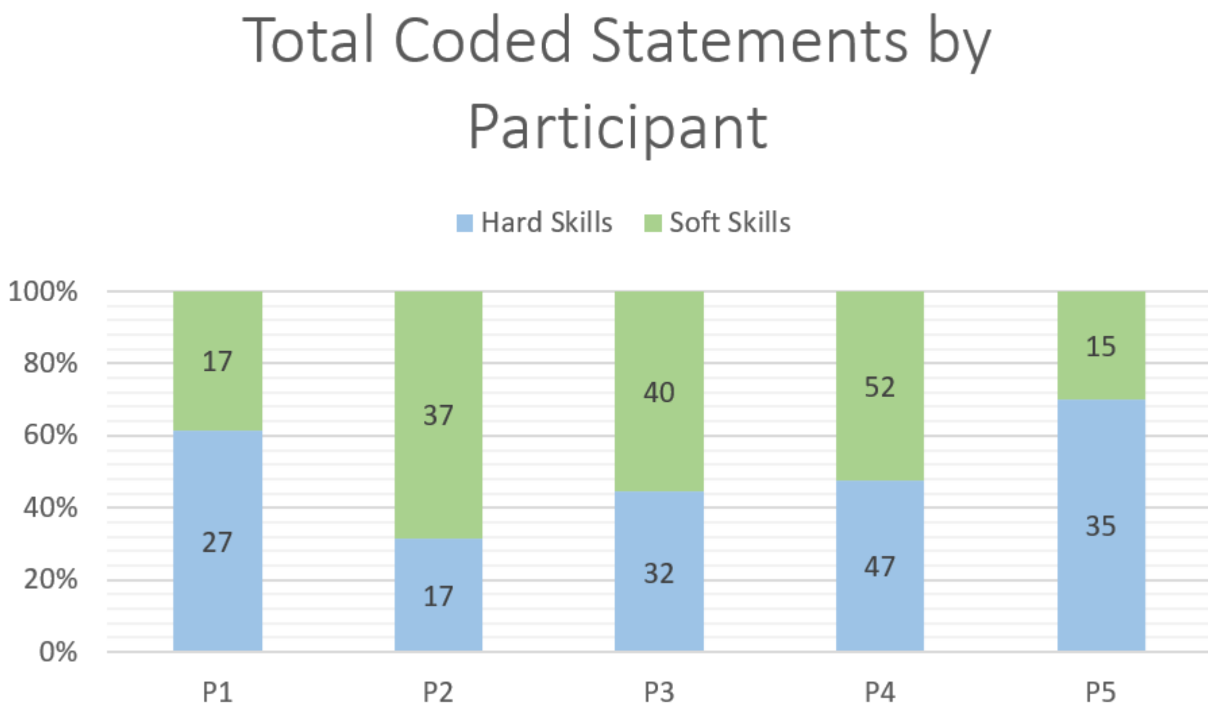

Figure 3: Histogram of total coded statements by participants, including a number and percentage breakdown of soft vs. hard skills mentioned.
NB: we observe significant differences in total coded statements by teachers (e.g., P1 = 44, P4 = 99) because we allowed teachers to naturally speak about their teaching experience and surfaced these values from their statements instead of directly asking them about skills they valued.