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Assessing Emphasized Engineering Practices and Their Alignment with Engineers' Personal Values

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Introduction

Engineers' are increasingly tasked with addressing complex challenges that require both technical proficiency and an ability to understand and account for the broader human and contextual factors that shape and are shaped by engineering solutions. In response to this need, there have been numerous calls for engineers across a range of educational and professional contexts to develop systems thinking skills. Often within engineering, conversations of systems thinking disproportionately emphasize relationships between multiple technical components or a product or process compared to equally important considerations of contextual and human aspects of a complex problem. Considering human and contextual elements of complex engineering problems in addition to the technical aspects is important for several reasons. First, accounting for all of these types of factors can help ensure engineering solutions are effective, best meet the needs of stakeholders and affected communities, and avoid causing undue harm. In addition, centering social and contextual competencies in addition to technical ones as core aspects of engineering systems thinking may help promote broader participation in engineering, as research suggests socially-aware engineering work attracts a more diverse pool of engineers. Our team's work advances a conceptualization of comprehensive systems thinking in engineering, defined as "a holistic approach to problem solving in which linkages and interactions of the immediate work with constituent parts, the larger sociocultural context, and potential impacts over time are identified and incorporated into decision making."

In order to better understand and support engineers' development of comprehensive systems thinking skills, our team endeavored to understand the aspects of engineering work emphasized across a range of educational and professional settings. In addition, to understand the implications for engineers' continued participation in the field, we sought to characterize the extent to which emphasized aspects of engineering work aligned with engineers' personal perceptions of important or valuable aspects of engineering work. To do this, our team developed a card sort-based interview protocol in which participants were asked to sort through a list of 26 engineering practices to indicate those they felt were most and least emphasized in the particular engineering contexts in which they engaged and to discuss how these most and least emphasized practices aligned with their personal priorities and values. Our team developed both in person and virtual versions of this interview protocol that are adaptable to a range of engineering contexts and allow flexibility in data collection. In this paper, we provide a detailed overview of the two forms of this instrument, describe data analysis procedures, and report preliminary data from interviews with 18 undergraduate and graduate engineering students and practitioners from various fields using this instrument. These findings include the engineering practices identified by these participants as most and least emphasized in educational and professional engineering contexts as well as those practices they personally prioritize in solving a complex problem in their field. These findings provide insight into the systems thinking and other engineering skills that may or may not be fostered across different engineering spaces and identify instances of dissonance experienced by engineers related to the types of practices emphasized in a given setting that could potentially affect their engagement or persistence in engineering.

Background

Modern engineers are called to tackle an array of complex issues of regional and global significance—so-called Grand Challenges [1]—such as climate change and global health care. To fully address such issues, engineers must be able to identify and incorporate into their decision making all relevant elements of systems in which their work is contextualized. Employers, policy makers, and scholars call for promoting systems thinking in engineering education because it is an essential skill in addressing problems engineers face in practice as well as broader global problems [2] – [4]. In addition to being a seemingly core engineering skill, evidence suggests systems thinking is also linked to students' development of other core engineering competencies. In a national study of undergraduate engineers, results showed that curricular emphasis on systems thinking was positively related to students' design and interdisciplinary skills [5].

Existing work on engineering systems thinking tends to emphasize the ability to recognize constituent technical elements and parts of an engineering problem (e.g., [6] – [8]), but not how these constituent elements and parts are embedded in broader economic, sociocultural, and temporal contexts and how all of these must collectively inform decision making. This emphasis stands in contrast to discussions of systems thinking in other fields (e.g., [9], [10]) and more recent work in engineering [11], which emphasize consideration of relevant broader contexts as a critical element of systems thinking. Our team's work begins with an assumption that systems thinking within engineering requires attention to technical, relational, contextual, and temporal dimensions. Research is needed to understand how engineers are trained, if at all, on all key aspects of engineering systems thinking

A lack of attention to social and contextual aspects of engineering systems thinking may reflect an underemphasis on these dimensions in engineering education more broadly. A nationally representative study of engineering instructors and administrators showed that both program chairs and instructors reported their programs and courses gave only slight to moderate emphasis on understanding how engineering solutions could be shaped by social, environmental, political, and cultural contexts or considerations, despite acknowledging the importance of such emphases [12]. Relatedly, in a longitudinal study of undergraduate engineering students, Cech [13], [14] found that students' beliefs in the importance of professional and ethical responsibilities, awareness of the consequences of technology, understanding of how people use machines, and their social consciousness all declined over the course of their degree program. Additionally, these public welfare beliefs held by students were linked to their perceptions of the cultural emphases of their engineering programs. Thus, while engineers may be trained to draw connections and account for interrelated aspects of a problem, if their training generally overlooks key social and contextual dimensions of engineering, these dimensions may similarly be overlooked or underemphasized in applications of systems thinking.

Engineering systems thinking that recognizes not only complex technical interrelationships but also how these technical aspects of a problem are embedded in a larger social, environmental, economic, political, and cultural context, is critical for several reasons. First, accounting for all aspects of a problem is essential for ensuring safe and effective engineering solutions. There are countless instances in which engineering solutions were ineffective or even harmful when contextual and human factors were not fully accounted for in a solution. These examples range from widespread pollution arising as a result of the Industrial Revolution to an increase in serious injuries such as spinal fractures and paralysis among football players after the development of modern protective gear that enabled more aggressive tackling and the use of heads to hit opponents [15]. In addition, research suggests that socially engaged engineering work that considers the broader sociocultural context in engineering activities attracts a more diverse population of engineers than other engineering work [16], [17] and women and minority students are more likely to emphasize communal goals and community-oriented outcomes in choosing to pursue a particular type of work [18] – [21]. However, students often perceive a disconnect between these interests and the type of work emphasized in engineering and other STEM professions [21] – [23]. More broadly, Litchfield and Javernick-Will's [16] "I am an Engineer AND," argues that dominant engineer stereotypes are not aligned with more socially-aware, engaged engineering activities, and that "clear deviations" from this stereotype may encourage more individuals to choose to pursue or remain in engineering study. Their findings suggested that students invested in socially engaged engineering organizations were likely to reject the engineer stereotype because they felt their interests included engineering ***and*** broader social issues that students did not recognize as central to engineering. If students view their strengths and passions to lie outside core engineering work, they may feel alienated from the field. Understanding which aspects of engineering work are emphasized across various contexts and how these align with engineers' personal interest and values is important both for identifying potential barriers to full participation in engineering and ensuring engineering training provides a foundation for skill development related to all critical aspects of systems thinking.

Methods

Study Goals

Given the importance of promoting attention to a comprehensive array of engineering skills both in supporting broad participation in the field and as a key foundational element of engineering systems thinking that enables engineers to best address complex problems, our team developed and tested a tool to assess emphasized aspects of engineering work and their alignment with engineers' own values and interests. A primary goal of the present paper is to share this tool for use in future research. The tool described is a card sort interview activity (and a virtual adaptation of it) in which participants are provided with a selection of 26 engineering practices and asked to engage in a series of sorts to indicate those they perceive to be most and least valued in particular engineering settings in which they are participants as well as those practices they personally consider to be the most important. In addition to describing this tool and its development, we present preliminary findings related to the engineering practices perceived by student and professional engineers to be valued in various academic and professional engineering settings and how these valued aspects of engineering work aligned with participants' own priorities.

Interview Development and Content

The practices included in the card sort activity were derived from a systematic literature review of key qualities and competencies of engineers [24], our team's working definition of systems thinking, and feedback from undergraduate and graduate engineering students and engineering faculty. We solicited feedback on how well an initial list of practices aligned with engineers' own academic and professional engineering experiences and asked for suggestions of additional practices that were reflective of their experiences. In addition, our team reviewed responses from an earlier study phase in which participants identified types of engineering skills they felt were important in their work to capture those practices not on our original list [34]. Our team then sought feedback on the clarity of items through an informal focus group of undergraduate and graduate engineering students in one of the authors' labs. Finally, we conducted pilot interviews with an additional seven engineering students to further check clarity and comprehensiveness of the list of practices. Based on feedback from pilot interviews, we made several revisions to the activity, including adding several practices, clarifying language, and dropping or combining several practices perceived to be redundant. The final list of 26 practices represent a wide range of engineering activity, including research, technical skills, communication, design, and social/contextual awareness. A full list of engineering practices included in this activity is available in Figure 1. Each practice was assigned a randomly generated letter from A to Z to facilitate quick recording of practices named during the interview and practices were presented to participants in a randomly shuffled set (or arranged randomly on a screen in our digital adaptation of the activity).

1. Conduct research on fundamental engineering principles
2. Draw on science and engineering principles to predict outcomes
3. Analyze a problem and define the constraints
4. Collaborate with others by sharing expertise, ideas, resources etc. to achieve a common goal
5. Test and evaluate potential solutions
6. Manage work process across all stages of a project
7. Incorporate ideas and approaches from other fields of study when appropriate
8. Pitch your ideas and make a case for their value
9. Account for relationships between multiple elements or components of a project
10. Come up with innovative ideas and approaches for addressing a problem
11. Develop details or schematics of potential solutions
12. Account for potential future impacts in developing a solution
13. Prepare technical communication, including written and oral reports or use of figures to represent work
14. Demonstrate social awareness, empathy, and self-awareness in interactions with others
15. Follow proper data collection procedures
16. Account for ways natural environment may affect or be affected by one's work
17. Interpret data, such as results from modeling, validation, and other data processing
18. Develop plans and procedures for experiments

19. Build tangible artifacts as models, prototypes, or working products
20. Consider ethical responsibility
21. Negotiate tradeoffs in how different problem components or requirements can be addressed
22. Account for social or cultural context in which a project is embedded
23. Demonstrate leadership to ensure teams work effectively toward common goal
24. Communicate effectively about work with people from other academic or professional backgrounds in verbal or written form
25. Iterate on and improve on ideas or designs
26. Account for the immediate problem context as it relates to one's work

Figure 1: List of practices used in card sort interview activity

In order to be able to examine the aspects of engineering work emphasized in any given environment, our team developed an interview protocol used in conjunction with the list of practices described above in which participants are asked to look through the deck (or virtual display) of practices to identify the three to six practices they feel are most emphasized or valued and an additional three to six they perceived to be emphasized or valued in a given engineering context. Participants are asked a series of follow up questions after these card sorts. After discussing the practices emphasized in the engineering context(s) in which they engaged, participants are asked to sort through the deck once again to identify the top practices they personally deem to be most important in addressing a complex problem in their field. In addition, participants are asked to reflect on the extent to which the valued aspects of engineering work in their academic or professional contexts align with their personal engineering values as well as their opportunities to develop their competency at engineering practices important to them. The interview protocol is listed below. Depending on the number of contexts discussed in a given interview, questions 1-7 may be repeated for each unique context.

1. I'd like you to look through the list of practices and pick the top 3- 6 that you think were most emphasized or valued in your [context] experiences (to date), regardless of how important you personally think they were.
2. How can you tell these were the most valued or emphasized? (Can you think of any examples that highlight their importance?)
3. Were there any other practices or skills not included in the deck that you think were really valued in that setting? I want to make sure we're not missing something key to your experience.
4. How do you think those emphasized practices aligned with what you personally felt were the most important? (Are there things that you think are over- or under-emphasized?)
5. Can you now please identify the 3-6 practices that you think were the least emphasized or valued in [context]? Again, irrespective of your own opinions?
6. How can you tell these were the least valued or emphasized? (Can you think of any examples that highlight their importance?)
7. Did you participate in any groups, projects, or experiences within [context] where you got the sense different types of practices were emphasized? (Prompt: In what ways? How does that compare to your experiences in [context] overall in terms of how well it aligns with the things you personally prioritize?)

8. Now, I want to get your perspectives on the practices that are most important. Which five of these practices do you **personally** consider to be the most important in terms of solving complex problems in your field? Why?
9. How do you think what was emphasized in your [educational/work/research/team] experiences align with these things? (I noticed there is/is not overlap…)
10. Do you feel your personal skills and perspectives were generally recognized and valued in [context]? How so or in what ways were/weren't they?

This semi-structured card sort interview is intended to prompt reflection both on the aspects of engineering practice (de)valued in particular contexts and on participants' experience of alignment or dissonance between their personal engineering values and priorities and those of the engineering contexts in which they engage. A copy of the interview protocol and templates for the in-person and digital versions of the tool can be found online at: https://dalyresearch.engin.umich.edu/design-and-education-tools-and-workshops/.

Participants and Data Collection

The card sort interview described above was initially conducted as the second part of a two-part follow up interview with a subset of participants from an earlier phase of our team's study focused on engineers' approaches to solving complex engineering problems. Participants in the original study phase were recruited based on their prior experiences solving a complex problem, defined broadly to allow for both student and professional engineering participation. In addition, participants were screened to ensure diversity in both demographic traits and the nature and extent of prior engineering experiences.

The preliminary data presented in this paper come from interviews with 18 engineering students and practitioners recruited from the 50 participants in this first study phase and range from second year engineering undergraduates to advanced engineering professionals. Because one focus of the larger study in which these interviews were conducted was characterizing experiences in education contexts, the majority of participants were current undergraduate or graduate engineers or early career professionals who could also reflect on their educational experiences, though several were advanced engineering professionals. Seven of the participants were women. Nine participants identified as White, four as Latinx and/or Hispanic, four as Asian, and one as African American. Because the larger study focus was on capturing a wide range of potential engineering experiences, participants were recruited from a wide range of engineering disciplines, including Computer Science, Mechanical, Biomedical, Electrical, Environmental, Industrial, and Materials Engineering. Student participants were enrolled either at a large selective public research university or a smaller regional public university.

The interviews described above were conducted following a distinct initial portion of the interview, which consisted of a think-aloud activity in which all participants were asked to respond to a hypothetical engineering problem provided by the researchers. In total, these two-part interviews took participants between 43 and 80 minutes to complete, with the card sort portion of the interview generally taking about two-thirds of the total interview time. Interviews took place in person in a mutually convenient location, often in a conference room on campus, in the participant's office, or at a public location such as a library or coffee shop. Interviews were audio recorded and later transcribed, using the Rev.com transcription service.

Data Analysis

The preliminary data analysis presented in this paper focuses only on summarizing trends in the particular practices participants perceived to be emphasized across different engineering contexts and how these compare to those practices they reported personally valuing most highly in their own work. Subsequent analyses focused on characterizing in more detail engineers' differing levels of prioritization of various aspects of engineering work and the degree of dissonance they perceived between their personal emphases and those of the engineering environments in which they engaged are reported elsewhere [34]. Analysis of the data presented in this paper included reviewing interview note sheets, supplemented by interview transcripts when necessary, to note which of the 26 practices each participant identified as most and least valued in their different engineering environments and the practices they personally identified as most important in solving a complex problem in their area in their responses to the card sort task. These responses were compiled into a spreadsheet, which facilitated an examination of trends in the practices participants perceived to be most and least emphasized in various engineering contexts and the extent of alignment at both the aggregate and individual level between these emphasized practices and those participants' identified personally as most important.

Digital Version

While the original card sort interview protocol was developed and initially conducted in person, our team also adapted this interview activity to a live virtual format, using Google Jamboards. Rather than being presented with a deck of index cards to sort through, participants are sent a link to a Jamboard with the 26 practices arranged as a bank at the bottom. They are then able to indicate those practices they perceive to be most and least emphasized by dragging those practices into the corresponding boxes displayed at the top of the screen (See Figure 2). Each Jamboard can contain multiple screens with the same list of practices (displayed in different colors for easy distinction between screens/sorts) to enable participants to conduct multiple sorts to reflect different contexts, as well as those practices participants personally identify as most important (containing only a single box labeled "Personally Most Emphasized" for sorting at the top of that screen). The interviewer is able to see participants' selections in real time while the participants are guided through a discussion of the practices they identify, using the protocol provided above.

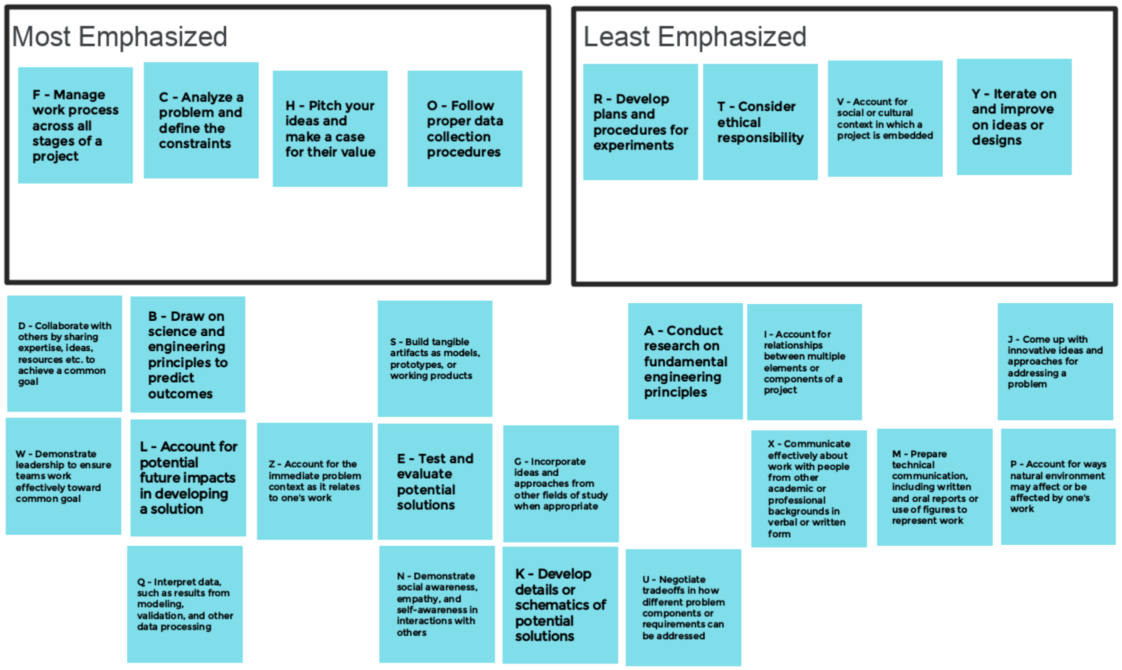

Figure 2: Screenshot of digital version of card sort activity

Findings

The preliminary findings reported in this paper, while not intended to be representative of the field of engineering as a whole, illustrate how the card sort interview activity described above may be used to understand what is (de)emphasized in various engineering contexts and explore the implications of such emphases for engineers' learning, work, and perceptions of themselves in the field. From the sample of 18 engineering students and practitioners, the findings highlight the most and least emphasized practices in engineering education and professional settings and how these compare to those participants personally identified as most important. For each of these, we highlight those practices for which 30 percent of respondents in a given category (e.g. professional experience, undergraduate experience) indicated as most, least, or personally emphasized as an indication of some degree of shared perspectives among respondents.

Most and Least Emphasized Practices in Education

The engineering practices participants most commonly cited as highly emphasized and valued in undergraduate and graduate engineering education experiences included *preparing technical communication, analyzing a problem and defining the constraints, interpreting data*, and *collaborating with others to achieve a common goal*. Roughly a third or more of respondents reflecting on their undergraduate and graduate educational contexts identified these as the practices they perceived to be most highly emphasized in their education. Within undergraduate contexts, over 30 percent of (five or more) respondents also named *testing and evaluating potential solutions, building tangible artifacts*, and *drawing on science and engineering principles to predict outcomes*. In graduate contexts, *developing plans and procedures for experiments, coming up with innovative ideas*, and *conducting research on fundamental* *principles* were named as highly emphasized by more than 30 percent of (three or more) respondents. Table 1 shows a summary of the practices participants cited as the most and least emphasized across undergraduate and graduate education contexts.

Participants similarly identified the practices they felt least emphasized or valued in their engineering education experiences. In both undergraduate and graduate education contexts, over 30 percent of respondents perceived *demonstrating social awareness and empathy in interactions with others, incorporating approaches or ideas from other fields,* and *accounting for the social or cultural context in which a problem is embedded* to be the least valued or emphasized engineering practices. In addition, within undergraduate education, over 30 percent of respondents identified *negotiating tradeoffs in how different components or requirements can be addressed* as among the least emphasized practices. In graduate education contexts, *accounting for future potential impacts, accounting for the natural environment in one's work*, and *demonstrating leadership to ensure teams work toward a common goal* were named by 30 percent or more participants as least emphasized or valued. Notably, the majority of practices participants perceived to be least valued in engineering education contexts relates to interpersonal, contextual, and interdisciplinary awareness.

Table 1: Practices Most and Least Emphasized in Educational Contexts

	Proportion of participants identifying practices as…			
	Most Emphasized In		**Least Emphasized In**	
Practice Description	**Undergrad (n=16)**	**Grad (n=10)**	**Undergrad (n=16)**	**Grad (n=10)**
Prepare technical communication, including written and oral reports or use of figures to represent work	0.63	0.70	0.13	0.10
Analyze a problem and define the constraints	0.56	0.40	---	---
Interpret data, such as results from modeling, validation, and other data processing	0.38	0.60	0.06	---
Collaborate with others by sharing expertise, ideas, resources etc. to achieve a common goal	0.38	0.30	0.06	---
Test and evaluate potential solutions	0.44	0.20	---	0.10
Build tangible artifacts as models, prototypes, or working products	0.44	0.10	0.19	0.20
Develop plans and procedures for experiments	0.25	0.30	0.19	---
Conduct research on fundamental engineering principles	0.19	0.40	0.19	0.10
Draw on science and engineering principles to predict outcomes	0.31	0.20	0.13	---
Develop details or schematics of potential solutions	0.25	0.20	0.06	---
Negotiate tradeoffs in how different problem components or requirements can be addressed	0.19	0.20	0.31	0.20
Account for social or cultural context in which a project is embedded	0.19	0.10	0.31	0.40
Come up with innovative ideas and approaches for addressing a problem	0.06	0.30	0.19	---
Iterate on and improve on ideas or designs	0.19	0.10	0.13	0.10
Communicate effectively about work with people from other academic or professional backgrounds in verbal or written form	0.13	0.20	0.06	0.10

Incorporate ideas and approaches from other fields of study when appropriate	0.13	0.20	0.31	0.30
Follow proper data collection procedures	0.19	0.10	0.25	---
Pitch your ideas and make a case for their value	0.06	0.20	0.13	0.10
Consider ethical responsibility	0.06	0.10	0.19	0.10
Manage work process across all stages of a project	---	0.20	0.19	0.10
Account for potential future impacts in developing a solution	---	0.10	0.25	0.40
Account for relationships between multiple elements or components of a project	---	0.10	0.19	0.10
Account for ways natural environment may affect or be affected by one's work	---	0.10	0.25	0.30
Account for the immediate problem context as it relates to one's work	---	0.10	---	---
Demonstrate social awareness, empathy, and self-awareness in interactions with others	---	---	0.38	0.60
Demonstrate leadership to ensure teams work effectively toward common goal	---	---	0.19	0.40

Note: The practices in each column selected by 30% or more of participants are highlighted – Green for the most-valued practices, orange for the least-valued practices

Most and Least Emphasized Practices in Engineering Workplaces

Because the goal of the larger study was to investigate experiences of engineers across a range of levels of experiences, the sample included many undergraduate and graduate students, and fewer working professionals. Thus, not all participants had professional engineering experiences. Given this lack of professional experience by multiple participants, participants with experiences in engineering workplaces represented in the study are smaller in number (n=9) and their experiences varied widely, so any trends should be interpreted with considerable caution. Workplaces represented included those that focused on various aspects of medicine, military, engineering education, tooling, and automotive manufacturing. Across these various workplaces, a third or more (three or more) respondents identified *collaborating with others towards a common goal, accounting for the social or cultural context, demonstrating team leadership, coming up with innovative ideas, demonstrating leadership to ensure teams work effectively, building tangible models or prototypes*, and *effective communication with people from other academic backgrounds* as among the most highly valued or emphasized practices in their workplaces. Interestingly, *accounting for the social or cultural context* and was also cited by a third of participants with workplace experiences as one of the least valued or emphasized. This tension highlights the variation in engineering practices emphasized across these different professional contexts. A third or more respondents also cited *interpreting data* and *accounting for the natural environment* as among the least emphasized practices in their workplace. Table 2 displays full workplace results.

Table 2: Practices Most and Least Emphasized in Workplace Contexts

	Proportion of participants (n=9) identifying practices as…	
Practice Description	**Most emphasized in workplace**	**Least emphasized in workplace**
Collaborate with others by sharing expertise, ideas, resources etc. to achieve a common goal	0.56	0.11
Account for social or cultural context in which a project is embedded	0.44	0.33
Come up with innovative ideas and approaches for addressing a problem	0.44	0.22
Demonstrate leadership to ensure teams work effectively toward common goal	0.44	---
Build tangible artifacts as models, prototypes, or working products	0.33	---
Communicate effectively about work with people from other academic or professional backgrounds in verbal or written form	0.33	0.11
Manage work process across all stages of a project	0.33	---
Analyze a problem and define the constraints	0.22	0.11
Account for relationships between multiple elements or components of a project	0.22	---
Iterate on and improve on ideas or designs	0.22	0.22
Develop plans and procedures for experiments	0.22	---
Develop details or schematics of potential solutions	0.22	0.11
Account for the immediate problem context as it relates to one's work	0.22	---
Account for potential future impacts in developing a solution	0.11	---
Consider ethical responsibility	0.11	---
Interpret data, such as results from modeling, validation, and other data processing	0.11	0.33
Test and evaluate potential solutions	0.11	---
Demonstrate social awareness, empathy, and self-awareness in interactions with others	0.11	0.11
Negotiate tradeoffs in how different problem components or requirements can be addressed	0.11	0.11
Incorporate ideas and approaches from other fields of study when appropriate	0.11	0.22
Conduct research on fundamental engineering principles	0.11	0.22
Prepare technical communication, including written and oral reports or use of figures to represent work	---	0.11
Account for ways natural environment may affect or be affected by one's work	---	0.56
Pitch your ideas and make a case for their value	---	0.22
Draw on science and engineering principles to predict outcomes	---	0.11
Follow proper data collection procedures	---	0.11

Note: The practices in each column selected by 30% or more of participants are highlighted – Green for the most-valued practices, orange for the least-valued practices

Personally Important Emphases and Alignment with Educational and Professional Emphases

Examining trends across participants' responses suggests mixed results in the extent to which the engineering practices deemed by participants to be most important align with those most emphasized in their educational and professional experiences. Common practices identified by over 30 percent (or more than six) of all 18 respondents as personally most important for addressing a complex problem in participants' respective fields included: *collaborating with others to achieve a common goal, analyzing a problem and defining the constraints, accounting for potential future impacts, considering ethical responsibility, accounting for the social or cultural context, interpreting data,* and *accounting for relationships between project components*. The practice most frequently named as personally important, *collaborating with others towards a common goal*, was among the practices respondents most commonly identified as highly emphasized or valued in their education and work experiences. *Analyzing a problem and defining constraints* and *interpreting data* were also among the practices often identified by respondents as emphasized in their undergraduate and graduate education contexts. However, several other practices named as personally important by participants, particularly those relating to the broader impacts of engineering work, were less commonly named as highly emphasized in participants' educational and professional engineering contexts. These practices included *accounting for potential future impacts,* which over 30 percent of respondents identified as among the least emphasized in their graduate education contexts, and *accounting for the social or cultural context* which was among the most commonly identified as least valued or emphasized in both education and workplace contexts (though also among the top valued in workplace contexts). While *accounting for relationships between project elements* and *considering ethical responsibility* were only named by a few participants as practices that were among the least emphasized in their educational or professional settings, few participants named these as among the most emphasized either. Table 3 displays the full results, sorted by the count of participants who named each practice as a personal priority in solving a complex problem in their field, and how those compare with the practices most and least emphasized in the engineering contexts in which they engaged.

Table 3: Practices Most and Least Emphasized by Participants and in their Educational and Workplace Contexts

	Proportion of participants identifying practices as…						
	Personal Emphases	**Most Emphasized In**			**Least Emphasized In**		
Practice Description	Personal (n=18)	UG (n=16)	Grad (n=10)	Work (n=9)	UG (n=16)	Grad (n=10)	Work (n=9)
Collaborate with others by sharing expertise, ideas, resources etc. to achieve a common goal	0.67	0.38	0.30	0.56	0.06	---	0.11
Analyze a problem and define the constraints	0.44	0.56	0.40	0.22	---	---	0.11
Account for potential future impacts in developing a solution	0.44	---	0.10	0.11	0.25	0.40	---
Consider ethical responsibility	0.44	0.06	0.10	0.11	0.19	0.10	---
Account for social or cultural context in which a project is embedded	0.33	0.19	0.10	0.44	0.31	0.40	0.33

Interpret data, such as results from modeling, validation, and other data processing	0.33	0.38	0.60	0.11	0.06	---	0.33
Account for relationships between multiple elements or components of a project	0.33	---	0.10	0.22	0.19	0.10	---
Come up with innovative ideas and approaches for addressing a problem	0.28	0.06	0.30	0.44	0.19	---	0.22
Test and evaluate potential solutions	0.28	0.44	0.20	0.11	---	0.10	---
Iterate on and improve on ideas or designs	0.22	0.19	0.10	0.22	0.13	0.10	0.22
Demonstrate social awareness, empathy, and self-awareness in interactions with others	0.22	---	---	0.11	0.38	0.60	0.11
Prepare technical communication, including written and oral reports or use of figures to represent work	0.22	0.63	0.70	---	0.13	0.10	0.11
Build tangible artifacts as models, prototypes, or working products	0.22	0.44	0.10	0.33	0.19	0.20	---
Account for ways natural environment may affect or be affected by one's work	0.17	---	0.10	---	0.25	0.30	0.56
Communicate effectively about work with people from other academic or professional backgrounds in verbal or written form	0.17	0.13	0.20	0.33	0.06	0.10	0.11
Negotiate tradeoffs in how different problem components or requirements can be addressed	0.17	0.19	0.20	0.11	0.31	0.20	0.11
Manage work process across all stages of a project	0.17	---	0.20	0.33	0.19	0.10	---
Develop plans and procedures for experiments	0.17	0.25	0.30	0.22	0.19	---	---
Pitch your ideas and make a case for their value	0.11	0.06	0.20	---	0.13	0.10	0.22
Demonstrate leadership to ensure teams work effectively toward common goal	0.11	---	---	0.44	0.19	0.40	---
Incorporate ideas and approaches from other fields of study when appropriate	0.06	0.13	0.20	0.11	0.31	0.30	0.22
Conduct research on fundamental engineering principles	0.06	0.19	0.40	0.11	0.19	0.10	0.22
Develop details or schematics of potential solutions	0.06	0.25	0.20	0.22	0.06	---	0.11
Draw on science and engineering principles to predict outcomes	0.06	0.31	0.20	---	0.13	---	0.11
Follow proper data collection procedures	---	0.19	0.10	---	0.25	---	0.11
Account for the immediate problem context as it relates to one's work	---	---	0.10	0.22	---	---	---

Note: The practices in each column selected by 30% or more of participants are highlighted – Blue for personally most important practices, Green for the most-valued practices, orange for the least-valued practices

Discussion

The card sort activity presented in this paper represents a way for engineering educators and researchers to identify the extent particular engineering contexts encourage a range of desired skills and emphasize practices that align with engineers' personal values or priorities, which has potential implications for engineers' learning and continued interest within the field [34]. Particular to engineers' development of comprehensive systems thinking skills, the card sort tool allows researchers to understand the extent to which various key systems thinking competencies – such as understanding relationships between components or accounting for the context in which a problem is situated – are perceived to be encouraged or valued in a given environment.

While not intended to be representative of all engineering contexts, the preliminary findings described above point to areas where perhaps more emphasis is merited, given participants' personal priorities and literature advocating for a wide range of engineering competencies (e.g., [25] – [28]). Broadly, these findings align with previous literature that suggests social and contextual aspects of engineering work are generally under-emphasized within engineering as a whole [29] – [31], an underemphasis similarly echoed in many discussions of systems thinking within engineering (e.g., [6] – [8]. In educational contexts, participants described technical communication, problem analysis and solution development, collaboration in teams, and several research-related practices as among the most highly valued. These emphases are largely consistent with students' reports of curricular emphases in their engineering programs in a nationally representative study of six engineering disciplines. Students in that study indicated that working effectively in teams, defining a design problem, and communication skills were among the engineering practices most highly emphasized in their curriculum [12]. Broadly, cultural and contextual aspects of engineering work, in addition to interdisciplinarity and social awareness, were among those most commonly perceived to be least valued in engineering education. Within the small and varied pool of professional contexts included in the study, many aspects of teamwork, communication, and collaboration were perceived to be highly valued, in addition to innovation and tangible building. Interestingly, consideration of the cultural context was named by over a third of participants as among the most emphasized in their workplaces and by another third as least emphasized. Participants' accounts of the practices they personally considered to be most important showed some alignment with the types of practices most emphasized in engineering – particularly related to collaboration, analyzing problems, and interpreting data. However, the respondents in this study generally seemed to be more likely to emphasize contextual aspects of engineering work – such as cultural context, future impacts, and ethics – than they perceived these to be valued in their education and work experiences.

While these findings suggest that engineers may have multiple opportunities to gain experience with some key skills essential for effectively addressing complex systems problems – such as the ability to work effectively in teams and carefully analyzing a problem and its requirements – opportunities to develop understandings of and experiences accounting for broader contextual aspects of complex problems appeared to be less common among study participants. If engineers receive consistent messages that such contextual considerations are peripheral or unvalued aspects of engineering practice more broadly, how will they learn to effectively integrate these critical skills as systems thinkers addressing multi-faceted and complex contemporary engineering problems? Our findings also highlight a disconnect between some participants' perceptions of how these contextual skills are valued in engineering education and professional settings and the degree of importance they personally place on such skills in their own work. If engineers perceive that only a narrow subset of technical skills are valued and essential to engineering work, the field risks alienating those engineers who place a high priority on and may be more adept at attending to social and contextual aspects of engineering work, a skill essential to effective engineering practice. This issue may be particularly concerning in light of research that suggests that groups consistently underrepresented in engineering education and practice may be disproportionately motivated by broader conceptualizations of engineering work [16] – [21].

Limitations

The present paper describes only an initial analysis of data collected from the interview protocol described and do not provide important contextual insight into how and why various practices are (de-)emphasized across various engineering settings nor how participants felt about the (mis-)alignment of these emphases with their own personal priorities and interests. Such nuance is important for fully understanding the significance and implications of the aspects of engineering work that are and are not valued across contexts. Further analyses, to be described in greater detail in subsequent papers, explore these considerations in greater depth. In addition, the limited number of participants and wide variation of engineering contexts described does not facilitate any sort of representative understanding about the practices (under-)emphasized in engineering as a whole. This is particularly true for professional engineering settings, as the data presented here includes a limited number of engineering practitioners from very different workplaces. Rather, the range of experiences described by participants in this study highlights the vast diversity in the local cultures and emphasized engineering practices across different educational and professional engineering settings, though all are located within the larger cultural context of the field of engineering. The study thus points to patterns in the types of engineering skills and knowledge perceived to be most valued across these different contexts and, most importantly, highlights how these emphases can be aligned or misaligned with the aspects of engineering work that engineers personally value.

Implications

Findings from this study suggest some potential implications for future research and practice. As with previous research (e.g., [12], [13], [30], [32], [33]) this study revealed a consistent pattern of an emphasis on technical and material aspects of engineering work and a general lack of attention to social and contextual dimensions and implications within engineering education settings. Further, while an underemphasis on these aspects of engineering work persists, many engineering students and professionals personally perceive a need for greater attention to social and contextual considerations. Given the importance of accounting for these dimensions for effective solutions to contemporary complex engineering problems, the findings raise questions about how educators might better integrate social and contextual aspects of engineering work into core engineering classes and better prepare engineers to be systems thinkers.

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