# Engineering for Social Good? How Professional and Educational Experiences Inform Engineers' Solutions to Complex Problems

by

Erika Mosyjowski

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Higher Education)
in The University of Michigan
2020

Doctoral Committee:

Associate Professor Shanna R. Daly, Co-Chair
Professor Lisa R. Lattuca, Co-Chair
Assistant Professor Erin A. Cech
Professor Vasti Torres

Erika Mosyjowski

emosy@umich.edu

ORCID ID:  0000-0001-5700-641X

© Erika Mosyjowski 2020

## Dedication

This dissertation is dedicated to my family for their unwavering and unconditional support in all that I do. To my parents, Kimberly and Joseph Mosyjowski, my siblings, Nikolas and Joan Mosyjowski, and my extended family, living and deceased, I love you all

**Acknowledgements**

There are so many wonderful people – family, friends, mentors, and colleagues – whose support has been invaluable as I have worked towards a PhD. I feel so very fortunate to have been surrounded by so many kind and brilliant people throughout this journey.

First, I would like to thank my committee. To my amazing co-chairs Shanna and Lisa, I would have considered myself lucky beyond reason to have even one mentor as supportive, generous, and kind as you each are, but to have you both in my life, and for the three of us to work together so well, I really cannot fathom how I can be so fortunate. I truly do not think I would have made it through this process without your guidance, understanding, and support of me both as a scholar and as a person, with all the very human messiness that entails. Vasti, I appreciate you stepping up to lend your higher education expertise to my very engineering-oriented dissertation, and for being so generous with your time and feedback even in the middle of a major move. Erin, I have admired your work for a long time and your research served to inform and deepen my interest in this area of study. I am so grateful to have had the opportunity to learn from you and for your feedback that has strengthened this study.

This research would not have been possible without those who offered up their time and stories to participate in this study – I am grateful for your generosity, trust, and openness. Thank you also to all those who provided feedback in focus groups and pilot studies and whose experiences and insight helped refine this study. In addition, I am so appreciative of the many colleagues who shared recruitment materials with their networks and helped connect me with participants – thank you!

I also offer my deepest gratitude to friends and colleagues across the University. First, to my wonderful cohort: thank you for your friendship over these past six years. I feel so fortunate to have had such a caring and fun group of folks to weather the ups and downs of this process with. You are each doing brilliant and important work and I cannot wait to see what you do next. I have also been lucky to be involved with both the Lattuca and Daly research teams, past and present. I have really valued the good work, learning, and friendships that have come from each. In addition, I am grateful for the many wonderful friends, colleagues, and mentors that comprise the larger CSHPE and Engineering Education communities and past colleagues in Rackham IR and the College of Engineering. I am so thankful for the relationships I have had the opportunity to build across these spaces and for all that I have learned within them.

I have also been fortunate to be propped up and cheered along by a number of amazing people outside the university community. First to Mark, for standing beside me throughout all the good and bad of this process. Your kind heart, patience, and understanding have made all the difference. Thanks also to the rest of the Wright family for being consistently welcoming and supportive. I am also grateful to have lifelong friends like Alyse and Christine – having friends to turn to and talk about anything, especially non-academic things, has helped keep me sane and connected to the things that are important. While she will never read this, thanks are also due to Muffins the cat for reminding me about the importance for taking time for snacks, snuggles, play, and sleep. I will thank you properly in the form of cat snacks and chicken.

Finally, to my family, I owe so much to you all.  To my extended family, wondering why on earth I was still in school but cheering me on regardless, thank you. Grandma, since I was young, our conversations always helped put the world in perspective and bring me so much joy. Joan, thanks to you for the frequent words of encouragement and offers of snacks. Nik, thank you for always being a reliable listener and steadying force and for keeping the house functioning when I could not. Mom and Dad, I cannot adequately thank you for the sacrifices you have both made to prioritize our educations and dreams. Your love, patience, understanding, and unconditional support in so many forms mean the world to me. Even on the most challenging of days, I am overwhelmed with gratitude for the truly remarkable family and larger community who have had my back every step of the way. Thank you all.

# Table of Contents

**Dedication** .......... ii

**Acknowledgements** .......... iii

**List of Appendices** .......... ix

**List of Tables** .......... x

**List of Figures** .......... xi

**Abstract** .......... xii

**Chapter 1: Introduction** .......... 1

**Contribution of Study** .......... 8

**Chapter 2: Relevant Literature and Conceptual Perspectives** .......... 11

**Background Literature** .......... 12

Underemphasis on Contextual Aspects of Engineering .......... 12

Emphasized Practices in Educational and Professional Settings .......... 13

How Engineering Emphases Shape Individuals' Experiences in the Field .......... 16

**Conceptual Framing** .......... 19

**Chapter 3: Methods** .......... 27

**Methodology** .......... 29

**Participants and Recruitment** .......... 33

Selection Criteria and Participant Characteristics .......... 33

First Phase Recruitment .......... 39

Second Phase Recruitment .......... 40

**Data Collection Protocols and Procedure** .......... 40

First Interview .......... 41

Second Interview .......... 43

**Data Management Plan** .......... 47

**Analysis** ....48
Chapter 4 Data Analysis ....49
Chapter 5 Data Analysis ....52
Chapter 6 Data Analysis ....54
**Limitations** ....55
**Trustworthiness of Data** ....57
**Chapter 4: Dominant Forms of Engineering Practice and Alignment with Participants' Values ....61**
Overall Patterns of Emphasized Engineering Practices ....63
Most and Least Emphasized Practices in Education ....64
Most and Least Emphasized Practices in Engineering Workplaces ....66
Personally Important Emphases and Alignment with Educational and Professional Emphases ....68
Alignment Between Engineers' Values and Educational and Professional Emphases ....71
Low Prioritization / Low Dissonance ....72
Low Prioritization / Moderate Dissonance ....74
Low Prioritization / High Dissonance ....76
Moderate Prioritization/Low Dissonance ....76
Moderate Prioritization, Moderate Dissonance ....78
Moderate Prioritization / High Dissonance ....80
High Prioritization / Low Dissonance ....81
High Prioritization, Moderate Dissonance ....83
High Prioritization, High Dissonance ....87
Summary of Findings ....92
Key Insights ....94
**Chapter 5: Factors Considered in Solving Complex Problems and Relevant Prior Experiences ....98**
Frequency of Factors Considered and Related Prior Experience ....100
Technical Considerations ....102
Immediate Conditions and Constraints ....107
Stakeholders ....115
Contextual / Social Considerations ....117
Team Coordination ....127
Interrelationships Between Components ....130
Summary of Findings ....132
Key Insights ....133
**Chapter 6: How Dominant Cultural Values Relate to Practice and Perceptions of Engineering ....136**
Description of Cases ....139

Nelson: Upper-level Undergraduate, Low Prioritization of Social/Contextual Aspects....140
Alek: Advanced Professional, Low Prioritization of Social/Contextual Aspects....145
Emerson: Early-level Undergraduate, High Prioritization of Social/Contextual Aspects....149
Leah: Early-career Professional, High Prioritization of Social/Contextual Aspects....153
Summary of Findings....157
Key Insights....159
**Chapter 7: Discussion and Implications....163**
Characterizing Dominant Cultural Values within Local Engineering Contexts....165
How Dominant Cultural Values May be Reproduced through Practice and Potential for Change....171
Engineers' Experiences and Consequences of Dominant Cultural Values....177
Limitations....183
Implications for Research....186
Implications for Practice....189
Conclusion....192
**References....193**
**Appendices....205**

# List of Appendices

**Appendix A: First Interview Participant Screening Questionnaire ........ 205**

**Appendix B: First Interview Protocol Draft ........ 207**

**Appendix C: Codebook ........ 210**

# List of Tables

Table 1: Summary of Goals, Sample, and Method by Study Component ....................28

Table 2: Participant Characteristics ....................37

Table 3: Engineering Contexts Discussed in Card Sort Interviews ....................45

Table 4: Practices Most and Least Emphasized in Educational Contexts....................65

Table 5: Practices Most and Least Emphasized in Workplace Contexts ....................67

Table 6: Practices Most and Least Emphasized by Participants and in their Educational and Workplace Contexts...69

Table 7: Categories of Factors, Definitions, and Count of Participant Mentions ....................101

Table 8: Count of Participants' Experiences Informing Consideration of Factors, By Category....................102

# List of Figures

Figure 1: Relations between history in person and history in institutionalized struggles (From Holland & Lave, 2009, adapted from Holland & Lave, 2001, p. 7) ........ 23

Figure 2: List of practices used in card sort interview activity ........ 45

Figure 3: Categories of participants, by prioritization of social/contextual aspects of engineering and expressed level of dissonance between personal values and emphases of engineering contexts in which they engage ........ 72

Figure 4: Categories of participants, by prioritization of social/contextual aspects of engineering and expressed level of dissonance, with source of dissonance between emphasis of engineering environments and personal values ........ 94

Figure 5: Alek, Emerson, Leah, and Nelson's categorization from Chapter 4 related to their prioritization of social/contextual aspects of engineering and expressed dissonance ........ 140

# Abstract

There have been a number of high-level calls for increased attention to contextual aspects of engineering work (including social, cultural, political, economic, environmental, and temporal considerations) as essential for ensuring the field can adequately address the complex problems of the modern world. However, the field of engineering – long grounded in a positivist tradition based on the primacy of technical considerations – has been slow to change. This qualitative study provided insight into how a persistent underemphasis on social and contextual aspects of engineering work in educational and professional settings is perpetuated, and how this underemphasis shapes the experiences of engineering undergraduate and graduate students and practitioners. Specifically, this study explored the aspects of engineering work emphasized in various local settings and the ways these informed engineers' day-to-day practice as a potential mechanism that explains how a narrowly technical model of engineering work that largely neglects contextual considerations of engineering problems, is reproduced. In addition, the study highlighted how the aspects of engineering practice emphasized in study participants' educational and professional settings (mis)aligned with their personal values and explored the implications of this misalignment for how these engineers viewed the field and their place within it. The study involved a two-phase design. Phase 1 was comprised of in-depth, semi-structured interviews with 46 engineering students and professionals from a range of academic and personal backgrounds about their experiences in solving a complex engineering problem, included the types of factors participants attended to in solving these problems. Phase 2 included follow-up interviews with a subset of 18 participants. The second phase used a card-sort task to identify the practices participants perceived to be most and least valued in the educational and professional contexts in which they had engaged and interview questions to elicit the ways in which these emphases did and did not align with their personal values and priorities. Analyses leveraged social practice theory (from the work of Dorothy Holland, Jean Lave, and colleagues) to explore the ways meaning and practice are negotiated within local cultures and the implications for how people and their actions are recognized and rewarded within those contexts. Findings from this study highlight the following: 1) the extent to which day-to-day engineering education and work overlooked social and contextual considerations, despite these being stated institutional and national priorities in engineering and priorities of many students and practitioners in the study; 2) how the neglect of contextual aspects of engineering training and work contexts was reproduced in the practice of these engineers when solving a complex problem; and 3) how the practices emphasized within engineering contexts varyingly aligned with participants' own values and the consequences of this (mis)alignment for their sense of their fit in the field. These findings have implications for both the ability of engineers to understand and meet the needs of a complex global society as well as for the field's ability to attract and retain a diverse engineering workforce.  Specific recommendations based on this study's findings include the importance of integrating contextual considerations throughout the core engineering curriculum and providing faculty and instructors the training and resources necessary to do so.

# Chapter 1: Introduction

As the field of engineering adapts to meet the demands of a diverse and ever-changing world, there is increased recognition that traditional notions of what engineers[1] do and who they are must be expanded. Specifically, there is growing recognition of the need for engineering programs to foster students' ability to identify and attend to contextual elements of problems, often referred to as contextual competence. These calls for curricular and instructional changes are linked by numerous scholars and policy makers to a need to educate socially responsible and engaged engineers (Amadei & Wallace, 2009; Catalano & Baillie, 2006; Lucena, Schneider, & Leydens, 2010; Moskal, Skokan, Munoz, & Gosink, 2008; UNESCO, 2010). ABET program accreditation criteria also include several student outcomes related to what some scholars have called contextual competence:

> c) An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability; f) An understanding of professional and ethical responsibility; h) The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context; j) A knowledge of contemporary issues" (ABET, 2017).

However, despite widespread calls for promoting a range of both technical and non-technical[2] engineering competencies as well as broadening participation in the field, the field is slow to change (Godfrey, 2014). In this study, I explore the cultural values related to various aspects of

---

[1] For the sake of brevity, I refer to both engineering students as professionals as "engineers" in this study, except where otherwise elaborated.

[2] Though I would challenge the idea that interpersonal, cultural, and contextual factors can and should be distinct from technical aspects of engineering work, I use this language to highlight the way this technical/non-technical dichotomy is often framed in engineering.

engineering work in different educational and professional contexts and how these relate to engineers' own practice of engineering and their perceptions of the field and their place within it.

Several recent studies have explored contextual competence in engineering— "an engineer's ability to anticipate and understand the constraints and impacts of social, cultural, environmental, political, and other contexts on engineering solutions" (Palmer, Terenzini, McKenna, Harper, & Merson, 2011, p. 1; Ro, Lattuca, Merson, & Terenzini, 2015, p. 36). The authors argue that while engineering solutions clearly need to be technically sound, they must also be feasible and desirable, which requires a consideration of the contextual constraints of the problem. They thus advocated for a consideration of the local, national, and global environments and how the needs or constraints of each level may relate to one another, proposing two sets of contextual constraints: "1) a potential design solution's scope (local, national, and global), and 2) the potential constraints to which the solution may require attention (historical, social, economic, environmental, political, cultural, and ethical)" (Palmer et al., 2012, p. 2). These studies focus on the need to build engineers' capacity to recognize and manage contextual factors in engineering design, but do not explicitly link contextual competence to the ways engineers may integrate both technical and contextual components in addressing complex engineering problems.

The separate attention in the literature to the technical and contextual elements of solving complex problems within the field of engineering mirrors a larger distinction often made in engineering between 'real,' that is, technical, engineering work and everything else. Nieusma and Riley (2010) point to the pervasive narrative in engineering that consistently equates technology with progress without examining its potential social consequences; this suggests that technical proficiency is the primary defining characteristic both for individual engineers and the profession of engineering. Faulkner (2007) referred to the tension between the analytical and human-oriented elements of engineering work as technical-social dualism. She argued the social competencies, though core in much professional engineering practice, are often devalued relative to the technical elements. Faulkner (2007) interviewed engineering practitioners who reported surprise at the fact that a relatively small proportion of their professional work consisted of technical or analytical tasks (which they described as "real" engineering) compared to their baccalaureate engineering training. She described a gendered engineering culture in which traditionally masculine, more physical or technical tasks associated with a technician engineer are more recognizably engineering work, even within industries that demand both technical and social competencies among engineers. This is consistent with a popular stereotype of engineers, which Tonso (2014) summarized as "socially inept sorts who are fascinated with gadgets and fixing things, more practical than scientists, and somehow brainier than technicians" (p. 1) and Kant and Kerr (2017) described as typically men "personally interested in 'how things work' and making stuff" (p. 702). Faulkner (2007) pointed to this stereotype as highlighting how social and technical competencies are viewed as mutually exclusive. To be technical, to engage in "real" engineering work, is to not be socially oriented.

In addition to the neglect of non-technical considerations as a key aspect of engineering work, some view a consideration of these factors as introducing undesirable bias into otherwise "pure" technical solutions (Cech, 2013). Neglecting the broader sociocultural context of engineering work, however, is not a value-neutral approach; a failure to consider this context may result in solutions that are not useful or, at worst, harmful. There are numerous examples of the potential for harm associated with technological development when contextual and human factors were not fully considered, from the pollution accompanying the Industrial Revolution to the increase in spinal fractures and paralyses among football players after the introduction of the modern helmet, which allowed players to use their heads to hit opponents (Tennner, 1997). Nieusma and Riley's (2010) study of two engineering design cases illustrates how, even in international engineering development or humanitarian work, a predominant focus on issues of technical functionality could result in engineering solutions that ultimately perpetuate social imbalances within the communities they are intended to benefit. They argued that the tendency to equate engineering with only its technical elements results in engineers overlooking the value of other kinds of expertise in addressing engineering-related problems as well as a tendency to overlook the importance of tending to matters related to process. They discussed these issues within the realm of engineering work in developing communities and cautioned about the risks of engineering solutions that neglect context:

> When development assistance is understood as providing a 'technological fix' – and insofar as technology is understood to be context-independent – a host of barriers to participation by intended beneficiaries arise 'automatically,' that is, without deliberate effort or intention (p. 56).

Nieusma & Riley's (2010) study demonstrated the consequences of attending to the product over social context and how this limits the usefulness of solutions for the intended beneficiaries. One case described a collaboration between several US and Nicaraguan universities to address issues of poverty in a particular Nicaraguan community. Though the project began with the explicit intent to learn from members of the community and account for local context throughout the process, a variety of factors resulted in an ultimate focus on the product or solution, with only superficial engagement with the community. Ultimately, this resulted in a project focus on entrepreneurship and product innovation as a solution to local poverty that neglected the local economic context with virtually no discussion of the country's efforts to move away from a capitalist free-market economic model.

In addition to the implications of neglecting social context for engineering work, the primary emphasis on technological aspects of engineering may also have implications for who is initially drawn to the field, who is encouraged or recognized for their work, and who ultimately decides to persist in engineering. There are well-documented disparities in the enrollment and persistence of women and racially/ethnically minoritized students within engineering education and work. A report by the National Science Foundation and National Center for Science and Engineering Statistics (2019) showed that while women earn over half of all undergraduate degrees, they earned only 20.9% of all bachelor's degrees in engineering in 2015. The share of women engineers in the workforce is even lower. While females comprise 47.7% of the total workforce, they account for only 29% of the broader science and engineering workforce and a mere 15.6% of engineering professionals. Similar conditions apply to racially/ethnically minoritized students. Racial/ethnic minorities represent over 30% of the United States population and 19.9 % of all engineering freshman enrolled in 2015. However, in 2016 (the last year graduation data is available), these students accounted for only 13.9% of engineering bachelor's degrees compared to a 20.4% share of all bachelor's degrees awarded in 2016 and 22% of those across all science and engineering fields. On average, racial/ethnic minorities make up approximately 19 percent of the current engineering workforce. These persistent disparities, which for many groups seem to grow wider between undergraduate engineering education and entering the workforce, raises questions about the characteristics of the field of engineering, and undergraduate engineering education in particular, that may influence these students' choices to pursue and persist in engineering.

The messages women and racially/ethnically minoritized students receive about the nature and purpose of engineering work may offer a partial explanation for these disparities, as well as why other students may leave the field. 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 (Litchfield & Javernick-Will, 2015; Swan, Paterson, & Bielefeldt, 2014) 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 (Chesler & Chesler, 2002; Colvin, Lyden, & León de la Barra, 2012; Fraser Bedoya-Valencia, & DePalma, 2013; Smith, Cech, Metz, Huntoon & Moyer, 2014). However, students often perceive a disconnect between these interests and the type of work emphasized in engineering and other STEM professions (Diekman et al., 2011; Gregory & Hill, 2000; Smith et al., 2014). More broadly, Litchfield and Javernick-Will's (2015) article, entitled, "I am and 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.

In this study, I endeavor to contribute to a greater understanding about the cultural beliefs related to valued aspects of engineering work in different engineering settings and how these shape individuals' practice of engineering within the context of solving complex problems as well as their perceptions of the field and their place within it. My focus on understanding these emphases related to complex engineering problems specifically reflects the array of complex issues of regional and global significance—so-called Grand Challenges (National Academy of Engineering, 2017)—such as climate change and global health care, that engineers must address. Addressing these complex issues requires engineers attend to all relevant aspects of a problem, including the broader context in which the problem is situated. I pay particular attention to the extent to which engineers are accounting for social and contextual aspects when solving complex problems, the importance they personally place on these aspects, and the extent to which such emphases are encouraged in the engineering contexts in which my participants engage.

Ultimately, I seek to understand why an underemphasis on social and contextual aspects of engineering work persists in engineering, despite calls for change. How is this narrowly technical model of engineering work reproduced? I look specifically at the aspects of engineering work emphasized in various local engineering settings and how these may inform engineers' day-to-day practice in these settings as one potential way this reproduction occurs. Further, I seek to understand how an underemphasis on social and contextual aspects of engineering work is experienced by engineering students and practitioners and the extent to which dominant values related to engineering practice (mis)aligns with individuals' personal values. In effort to address these larger goals, I explore the following specific research questions:

RQ1: What engineering practices do participants perceive to be most and least emphasized in the engineering contexts in which they engage?

RQ2: How do these emphasized practices align with those practices and values participants personally consider to be most important?

RQ3: What types of factors do engineers in my study most commonly attend to in addressing complex engineering problems?

RQ4: What educational, professional, and personal experiences do engineers cite as influential in their consideration of various factors when solving engineering problems?

RQ5: How do engineers negotiate their personal values and prioritized aspects of engineering within the engineering contexts in which they engage and how does this relate to their practice and perceptions of engineering?

I draw on social practice theory (e.g. Holland, Lachicotte, Skinner, & Cain, 1998; Holland & Lave, 2001; 2009) to frame my study and interpret my findings. Social practice theory describes how meaning and practice are negotiated within local cultures and have implications for how people and their actions are recognized and rewarded within those contexts. Data for the study included: 1) semi-structured interviews with engineers about their past experiences related to solving a complex systems problem and 2) follow up interviews with a subset of participants that included card sort activity in which participants were asked to describe the practices emphasized in their educational and professional experiences and how these aligned with their own values and engineering practices they personally consider to be most important.

**Contribution of Study**

While empirical literature provides insight into how the cultures and practices of particular engineering communities shape understandings of engineering work and the ways individuals may or may not identify or be identified as engineers, there has been little focused study of how an individual's experiences in different engineering contexts shape that individual's engineering practice. An emphasis on what influences both beliefs about engineering work and actual engineering practice may be critical to transforming engineering work so it better aligns with the needs of our changing society. We know that, despite top-down calls for increased attention to social contexts, the field is slow to change. Cech (2013) suggests engineering students and professionals will not be motivated to consider social issues if such issues are treated as supplemental to engineering practice and calls on engineering educators to consider how they might deconstruct and challenge ideas that technical engineering work can exist distinct from its social implications. Consistent with this call, I endeavored to do two things.

First, by highlighting the potential relevance and value of socially-aware elements of engineering practice, I hope to support full participation in engineering by a diverse group of engineers who may be more likely to be drawn to these elements of engineering work. Pushing on historically narrow conceptualizations of engineering work to include awareness and consideration of sociocultural contexts may help make engineering more appealing to those who perceive engineering practice as exclusively focused on technical knowledge and skills and narrowly focused on the immediate problem space. Second, by exploring the relationship between individuals' experiences in particular engineering contexts and their own approaches to engineering work, I hope to contribute to our understanding of the potential barriers and opportunities to broadening the definition of engineering practice, specifically related to solving complex problems. I seek to understand influential experiences for individuals, both within and external to engineering contexts, that shape what they attend to in an engineering problem. Individuals' life prior to and outside engineering schooling and work contexts may contribute to their approach to solving complex engineering problems. It is also possible that experiences in particular engineering contexts contribute to individuals' breadth of focus in addressing engineering problems, which would be of particular value when those experiences contribute to the development of certain skills and knowledge, such as contextual competence, that may not be emphasized in many engineering contexts. In turn, individuals with these experiences may gradually contribute to change in the field, through bringing their experiences and knowledge into their practice within all of their engineering communities.

## Chapter 2: Relevant Literature and Conceptual Perspectives

There is substantial literature suggesting that the technical aspects of engineering work have generally been both most visible and most valued (e.g., Faulkner, 2007; Nieusma & Riley, 2010), although there may be variation within particular educational and professional engineering contexts. Prioritization of technical engineering (at the global or local level) and subsequent neglect of other aspects, such as interpersonal and contextual factors, can have implications for the quality and appropriateness of engineering solutions. The neglect of social and contextual factors of engineering may also alienate students or professional engineers who value these so-called non-technical aspects of engineering work. Such findings raise questions about how these cultural beliefs that exist within many engineering contexts may shape the experiences, perceptions, and practice of the engineers learning and working in these spaces. The empirical literature reviewed in this section provides some insight into the ways widespread beliefs about the nature of engineering work and the ways these beliefs inform local engineering culture shape individuals' perceptions of engineering and identities as engineers. I aim to contribute deeper understanding of the of various engineering contexts and individuals' perceptions of these contexts and their place within them as well as extend on existing literature to consider how individuals' experiences of engineering cultures shape their engineering practice. I draw on social practice theory perspectives that emphasize the ways cultures are constructed by and affect the beliefs and activities of individuals in those cultural contexts to inform my analysis. In this chapter, I offer an overview of the empirical and theoretical literatures that provides the basis for the conceptual framing of the current study.

## Background Literature

### *Underemphasis on Contextual Aspects of Engineering*

Research suggests several widely-held beliefs about the nature of engineering work that potentially inform individuals' ideas of what it is to be an engineer and the way they personally practice engineering. As noted, a persistent perception within the field of engineering is of the division of the technical and non-technical elements of engineering work, with technical work being widely recognized as legitimate engineering work and interpersonal, social, and contextual elements often being relegated to the "other" or considered "soft skills" (Faulkner, 2007; Nieusma & Riley, 2010). Williams (2002), an engineering historian, refers to this long-held idea that engineers' work falls in a distinct technical domain of knowledge which can be applied systematically to a number of technical problems as "the ideology of engineering." He argues that, historically, technical and social elements of engineering do not mix.

This skill division was evident in a nationally representative study of instructors' and administrators' espoused support for a broader approach to undergraduate engineering education with more comprehensive engineering knowledge and skillsets aligned with national calls such as "The Engineer of 2020" (Lattuca, Terenzini, Knight, & Ro, 2014). Most engineering instructors and administrators in the study agreed that engineering programs should encourage students to consider all relevant factors when solving problems, but 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. Even less curricular attention was given to ethical issues and on asking students to examine their beliefs and values and how those influence their ethical decision making. Moreover, attention to contextual factors was greatest in first-year and capstone design courses, but received only slight emphasis in required engineering courses and electives— that is, in the great majority of engineering courses. Reports from senior-year students in these same engineering programs corroborate these curricular emphases.

*Emphasized Practices in Educational and Professional Settings*

An abundance of evidence supports the assertion that academic disciplines are strong influences on the content and delivery of college courses (e.g., Becher & Trowler, 2001; Lattuca & Stark, 2009; Nelson Laird, Shoup, Kuh, & Schwarz, 2008; Smart, Feldman, & Ethington, 2000). These disciplinary cultures further shape the experiences of undergraduate students and their understandings about core aspects of engineering work through artifacts and course content (i.e., textbooks, lectures, homework, projects) and through interactions with faculty and peers inside and outside the classroom. In their book-length study utilizing national level data, Smart et al. (2000) presented strong support for the role of disciplinary environments as socializing mechanisms for both faculty and students. Their findings show that discipline-based academic environments emphasize particular abilities, interests, and values; that they reinforce and reward these abilities, interests, and values; and that they consequently discourage others. These findings point to the role of the undergraduate curriculum as a primary vehicle for transmitting messages about important disciplinary competencies, interests, and values and providing educational experiences that seek to build these competencies, interests, and values (Lattuca & Stark, 2009). In a study of the role of engineering disciplines on curricular change, Lattuca, Terenzini, Harper, and Yin (2010) found evidence that both disciplinary *and* institutional factors influenced engineering faculty members' attitudes and behaviors related to curricular change. These findings suggest that academic cultures are shaped by institutional as well as national and international disciplinary/professional cultures.

Other scholars attribute beliefs such as the dismissal of contextual or social elements within engineering to differences between engineering education and professional engineering workplaces and what aspects of engineering work students are exposed to. Research suggests that narrow engineering education experiences, in which success is often measured by performance in textbook-, problem set- and test-based courses, results in students being unaware of, or discounting the importance of the non-technical, team-based aspects of engineering work (Stevens, Johri, and O'Connor 2014; Stevens, O'Connor, & Garrison, 2005; Stevens, O'Connor, Garrison, Jocuns, & Amos, 2008). Such studies suggest that students may lack exposure to, and thus images of, these elements of engineering work. They further suggest two potential risks of this lack of exposure: the first is that many students neglect to account for social and cultural aspects in their engineering work, while the second is that those individuals who place a strong emphasis on these aspects may feel compelled to leave engineering entirely, despite their course performance. In a longitudinal ethnographic study of engineering students, Stevens et al. (2008) describe the case of Bryn, a successful engineering student who nearly left the field because of her interest in advancing the social good and frustration with the competitiveness and emphasis on problem-solving speed in undergraduate engineering education. In contrast to these depictions of undergraduate engineering work, several studies suggest professional engineering work is often perceived as more heterogenous, the term used by Science and Technology Studies scholar John Law to describe how the social and technical elements of any engineering project are inextricably linked. These studies suggest this difference reflects the fact that workplace problems are often poorly defined and are shaped from the outset by a number of non-technical considerations such as budget and customer satisfaction (Jonassen, Strobel, & Lee, 2006; Rittel & Weber, 1973). Successfully addressing such problems necessitates communicating technical concepts to others (Korte, Sheppard, & Jordan, 2008) and often depends on coordination between individuals with different perspectives to complete the work on time. Trevelyan (2007) dubs this work "technical coordination," and highlights how a hybrid of technical and social aspects of engineering work are at the core of engineering practice. Stevens et al. (2014) contrast these forms of professional engineering work to the technical, generally well-structured engineering problems emphasized in undergraduate engineering training.

However, even if a heterogenous model of engineering work is perceived to be more necessary in professional contexts, there is ample literature that suggests many beliefs about engineering, including the disproportionate emphasis on technical work, are pervasive throughout the field in both educational and professional contexts. In an overview of engineering mindsets, Riley (2008) suggests engineers tend to learn to think analytically in the context of technical analysis, breaking down problems into small parts and then reassembling them. She argues the field does not place enough emphasis on thinking critically about the task at hand or how the task relates to the larger social context. Riley further argues that the field of engineering is also heavily influenced by positivist epistemology, which she links to a belief in technological determinism, that is, the assumption that technological development is self-driving and shapes society, an assumption which neglects the ways society constructs technology. A positivist perspective also frames science as objective in its methods and procedures, if not in its intentions, and many engineers view their work as objective as well due to its scientific basis, thus leaving unexamined their own responsibility for how their work may ultimately be used. Indeed, even in light of the scientifically-driven destruction of World War II, which included the use of gas chambers and the atomic bomb, the scientific community argued the technology behind such applications was neutral and advocated for scientific work to progress in a manner removed from public influence or oversight (Carter, Dueñas, & Mendoza, 2019; Harding, 2015). Cech (2013, 2014a) further examines a belief that science and engineering are "pure," that is, that they are removed from any political or social considerations. She refers to this ideology as the "depoliticization" of engineering and argues this ostensive ability of engineers to make value-neutral decisions, grounded only in technical considerations, has been a defining feature of the profession since the mid-nineteenth century and persists for many engineers today.

*How Engineering Emphases Shape Individuals' Experiences in the Field*

These widespread, enduring cultural beliefs about engineering work serve as foundational knowledge for new engineers learning about their field. Through their participation in various engineering contexts, individuals are socialized to understand that certain types of practice constitute engineering, both in their local context and more broadly. In a longitudinal study of undergraduate engineering students, Cech (2014a, 2014b) 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 decline over the course of their degree program. Additionally, she found that these public welfare beliefs held by students were linked to their perceptions of the cultural emphases of their engineering programs. For instance, when students believed their engineering programs placed little emphasis on ethical and social issues, their personal valuation of the public welfare beliefs was more likely to also be low. The decline in these students' public welfare beliefs did not reverse once students entered the workforce; rather, Cech (2014b) found importance ratings stagnated or worsened after graduation. This finding suggests that the engineering beliefs described above are not merely a function of a disconnect between engineering training and the nature of professional engineering practice, but prevalent in engineering practice as well. Cech and Sherick (2015) highlight how students are socialized into the culture of engineering through the curricular structure of engineering education, which they argue reinforces the ideology of depoliticization and shapes students' engineering identities and beliefs about their responsibilities as future professional engineers.

Cech and colleagues' work points to the significance of differences in cultural values between particular engineering organizations or communities, though these communities are still situated in the broader social context of engineering work. Humanitarian or service-oriented engineering organizations, for instance, often explicitly espouse their public welfare values. In their work, "I am an Engineer AND," Litchfield and Javernick-Will (2015) compared the personality and motivations of students participating in one such humanitarian engineering organization, Engineering without Borders, with those of non-participants and found some differences between the two groups. This study highlights how more socially-engaged students may be drawn to particular engineering communities, or how these communities develop such interests in their members. However, perhaps more enlightening is the study's framing of the "AND" - that is, how humanitarian, social justice, and broad interests are held in addition to, or contrast with, the heart of engineering work. Many study respondents in Engineering without Borders emphatically denied they were "typical" engineers, citing their broader interests, beyond technical aspects of engineering work.

Several empirical works have explored the ways engineering cultures shape how individuals identify and are identified by others as engineers. For example, in an ethnographic study of engineering students within one department of engineering, Tonso (2006) found that local categories of engineering identity signaled different forms of engineering practice that varied in the extent they were valued and recognized as real engineering work. Moreover, the extent to which individuals were perceived to embody different identities served as the basis of hierarchical power relations with real consequences for who was recognized as a "real" engineer. Two broad categories of engineering identities within the department included "nerds," who were technologically inclined but often lacking in social skills, and the more high-status "academic-achievers," students who "got the job done" (p. 288) and were perceived to have a good balance of academic and social skills. However, students did not perceive women engineers to fall into either of these widely recognized engineering identities, instead describing engineering women based on their attractiveness or social affiliation with Greek organizations. This hierarchy of identities resulted in gendered patterns of recognition and opportunity, in which women, as well as male students demonstrating engineering practices associated with more feminine engineering identities, were less likely to be recognized by their peers for their engineering work, despite their key contributions on their engineering project teams.

Danielak, Gupta, and Elby (2014) also demonstrated how the most valued, visible ways of thinking and problem-solving in a department, and individuals' self-perceptions in relation to these, could shape students' identification with the field. They highlighted the case of Michael, who described himself as "a fringe as far as students go" (p. 27) because his personal epistemology conflicted with what he perceived to be the dominant, most highly-valued approach to sense-making in his department. This study suggests that when an individual's self-concept or self-presentation to others does not align with the values of his or her local engineering culture, this disconnect can negatively shape that individual's personally held identity as an engineer and the likelihood of recognition as an engineer by others in that context, regardless of skill.

Disconnects between an individuals' identity as an engineer and that of the predominant cultural values of the engineering contexts in which they engage, whether felt by that individual or perceived by their peers, may have implications for an individual's sense of fit or belonging in the field. Derived from Bollen and Hoyle (1990), sense of belonging is defined as an individual's sense of social cohesion in a local context. Where Bollen and Hoyle studied neighborhoods, education researchers conceptualize the campus or program as the local context. Understanding of the antecedents of sense of belonging is limited, but research links elements of campus climates and cultures to students' sense of belonging to their campus communities (Museus, Yi, & Saelua, 2017). In educational contexts, students' feelings of belonging are associated with a number of outcomes, including achievement positive affective states and persistence in their program and field (Good, Rattan, & Dweck, 2012; Hausmann, Schofield, & Woods, 2007; Museus & Quaye, 2009; Smith, Lewis, Hawthorne, & Hodges, 2012; Walton & Cohen, 2011; Wilson et al., 2015). Within STEM fields in particular, research suggests that students' feelings of belonging has implications for their interest and persistence in the field, regardless of academic performance, particularly for women and students of color underrepresented in these fields (Good, Rattan, & Dweck, 2012; Johnson, 2012; Museus & Maramba, 2011).

## Conceptual Framing

The empirical literature described above highlights a number of ways that widespread cultural beliefs about engineering work have consequences for individuals' understandings of what constitutes engineering work and how they come to identify themselves and others as engineers. People develop such understandings and identities as they engage in cultural practices and social interactions with others, and with the tools and artifacts used in those practices and interactions, in their educational and work contexts. The conceptual perspectives that inform this work (Holland, Lachicotte, Skinner, & Cain, 1998; Holland & Lave, 2001; 2009) describe how local contexts are characterized by the practices that constitute those social worlds and the meanings attributed to these practices the linkages between these and the interpretations and identities of individuals engaging in those contexts. In their work "Identity and Agency in Cultural Worlds," Holland et al. (1998) describe identities within particular cultural worlds as "historical developments, grown through continued participation in the positions defined by the social organization of those worlds' activity" (p. 41). This framework, in addition to Holland & Lave's (2001; 2009) conceptually related social practice theory, points to the importance of considering how local cultures are constituted by and give meaning to practice within those spaces and provide a lens for understanding who and what "counts" in those spaces. These two closely related frameworks provide the conceptual orientation for my work, which focuses on these dynamics within an engineering context.

In my study, I examine the aspects of engineering practice emphasized within various engineering contexts, participants' perceptions of these emphases, and how their experiences in within and beyond these contexts, inform their engineering practice. Holland et al.'s (1998) conceptualization of "figured worlds" provides a useful explanation for the ways in which particular cultural contexts shape and give meaning to individuals' actions within those spaces (and how those actions are understood and interpreted by actors in those spaces). Holland et al. (1998) describe communities with particular cultural values or resources as "figured worlds." They define a figured world as "a socially and culturally constructed realm of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes valued over others" (p. 52). Thus, figured world shape and give meaning to individuals' actions within a given cultural space, and shape how individual actions are understood and interpreted by others in those spaces.

The concept of figured worlds is informed by activity theory, as described by Leontiev (1978), who argued that individuals are continuously and intentionally engaging with their environments, participating in socially meaningful activities. Further, a dialectical relationship between people and their environments through such activities, in which the things (whether tangible, like food, or intangible, like recognition as a particular type of person) that individuals desire or seek out from their environment are shaped by what is available to them or common within the environment. Holland et al. (1998) draw on this conceptualization of activity to make several points about figured worlds. First, they describe figured worlds as historical phenomena that individuals both enter into and continuously shape through their actions. Second, as with activities, figured worlds are social encounters between individuals with particular social positions. While individuals may fully learn and participate in some figured worlds, they may be excluded, or exclude others from, other worlds. Third, figured worlds are socially structured and constituted – their significance derives from being re-created by the activities of the participants (occupying particular roles) within them. Finally, as described previously, participation in figured worlds contributes to individuals' senses of self, in relation to multiple "landscapes of action" (p. 41).

Holland et al.'s (1998) description of figured worlds highlights how actions are imbued with meaning, with particular acts more recognized and valued in a given context. Their work also points to how the social context of a given environment shapes and is shaped by the activities of the individuals participating in it. Within engineering, an individual may be most motivated to engage in those engineering activities that will be recognizable and valuable forms of engineering practice within a particular academic or professional context. What is recognizable and valuable is, in turn, reinforced by the activities of members in that social context. If, for example, a non-profit engineering organization emphasizes assessing the impact of potential solutions to engineering problems on local communities as a key part of engineering work, employees of that organization may be more inclined to do this, understanding it as a (valued) element of engineering practice in that context and an available way to be recognized as an engineer within that specific organizational and cultural context. Over time, then, individuals' personal definitions of engineering work may come to more closely align with community understandings of engineering work.

Similarly, Holland and Lave's (2009) social practice theory emphasizes the relationships between the identities, experiences, and subjectivities individuals bring with them into a given context; the encounters between people as they enact cultural activities in that context (such as the practices of science or engineering within a particular academic setting); and the larger social forces (such as gender or racial inequality) that play out within locally situated interactions between actors with distinct life experiences and beliefs. The theory foregrounds the role of conflict and power; central to Holland and Lave's framework is the notion of local (contentious) practice, the everyday interactions between people with similar and differing histories and social positions and the inherent tension and conflict in these relations. Local practice is located within the larger historical, cultural, and political context, with these large-scale dynamics played out in ways particular to the local practice context. Individual actors also bring with them to this space their own intimate identities and subjectivities, which Holland and Lave refer to as "history-in-person" (p. 4, 2009). They explain, "Trans-local institutions are always being addressed under local conditions and on the basis of local actors' subjectivities. Thus, local practice is significant for the continuing formation of institutional arrangements in sociohistoric time/space" (p. 5). Larger social forces, such as gender or racial inequality, or beliefs about the technical nature of engineering work, play out in locally situated interactions between actors with distinct life experiences and beliefs. Practice and interactions within these local contexts serve to reinforce – or disrupt – these larger social forces. The relationship between the components of social practice theory is represented in Figure 1 below.

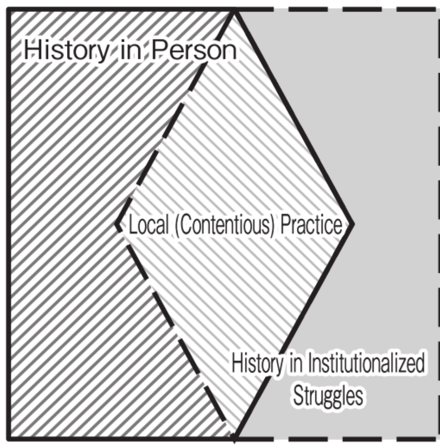


Figure 1: Relations between history in person and history in institutionalized struggles (From Holland & Lave, 2009, adapted from Holland & Lave, 2001, p. 7)

Social practice theory is characterized by several core assumptions. The first of these is that political, social, and cultural structures are produced and mediated through daily practices of individuals interacting within local contexts. Holland and Lave (2001) center identities in their analyses and characterize people and their identities as in process; individuals are not conceptualized as fully formed and static entities that are merely acted upon by larger social institutions, but rather as actors who negotiate both their identities and larger social institutions and forces within context. Individuals draw upon the cultural resources of a particular context – such as language, symbols, and shared meanings, to “author” themselves within these spaces. This self-authoring allows for vast individual differences while still accounting for the influence of social context – as individuals also bring with them their personal histories, cultures, and experiences in other contexts into a particular setting in which they are currently engaged. Power and privilege permeate the local contexts in which individuals negotiate meaning and these "enduring struggles" serve as a mechanism through which power and resources are unevenly distributed on the basis of dominant cultural values and broader social institutions such as race, class, and gender. While engagement in these spaces leaves individuals "vulnerable" to being identified or (mis)characterized by others, based on how closely aligned their practice and identities are with those most valued or recognizable in a given context, Holland and Lave (2001) argue that individuals can draw on their personal experiences and identities to create "alternate subjectivities" as a means of re-defining themselves and what it means for them to be an actor within a given context that may be counter to dominant narratives.

In the context of the current study, I argue that widely-held ideas about engineering work, such as the primacy of technical elements, permeate local engineering cultures. These ideas may be negotiated differently in different local cultures and by the actors within them, with these ideas being fully accepted in some contexts (perhaps implicitly), while directly challenged in others. In addition, I anticipate that individuals' participation across multiple engineering cultures and the life experiences they bring with them (their history-in-person) provide a repertoire of other values and skills that may uniquely shape their engineering practice within a given context. Some engineers may elect to embrace "alternate subjectivities," and practice engineering in a way not closely aligned with dominant values related to "what counts" as engineering work. However, there may be consequences for the way individuals think of themselves and are identified by others as an engineer should their forms of engineering practice differ substantially from the culturally valued forms of practice in that context. Individuals are likely to more comfortably identify and be recognized as a good engineer by others in a given setting when their practice aligns with the engineering skills and values emphasized in that setting. In addition to consequences for individuals' feelings about the field of engineering and their fit withing it, this extent of alignment may have implications for their advancement in the field, availability of opportunities, and power or influence within particular engineering spaces.

In summary, the literature and theoretical perspectives described above inform my thinking about how individuals' experiences within and external to specific engineering cultural contexts inform their engineering practice and provide the conceptual framing for the study I propose. First, as suggested by Holland et al. (1998), I assume that such a relationship between culture and practice exists – that particular cultural contexts shape and are shaped by the actions of individuals who engage in those contexts. I assume that different elements of engineering practice are varyingly recognized and valued in different engineering cultural contexts and that individuals acting within these contexts may be motivated to engage in those most available and valued forms of engineering practice. Local cultural understandings of engineering practice are, in turn, reinforced by the activities of those engaging in that context. Consistent with the perspective of Holland and Lave (2001; 2009), I assume that individuals participate in multiple educational and professional communities within engineering that have various, and potentially different, dominant values and practices. In addition, I assume these communities are located within and informed by a broader national culture of engineering work (which generally emphasizes engineering's technical aspects – see, for example, NAE, 2004) and that both local and national engineering cultures are situated in a wider historical, sociocultural, and political landscape.  For example, in addition to the overall disciplinary culture that shapes the communities in which engineers practice and learn about engineering, there are the local school and departmental cultures which may have similar different or additional values than the disciplinary community.  In addition, there are research groups or professional organizations within those departments that may emphasize particular values (such as University of Michigan's BlueLab and its emphasis on sustainable and socially engaged design) and shape the beliefs and practices of those who participate in them.

I do not assume that all engineers' practices necessarily align with the dominant values of the engineering communities within which they are situated. Individuals bring with them a host of other experiences that may inform their work, potentially from other engineering education or work settings, or from a range of other communities. I am particularly interested in how these life experiences intersect with their experiences in engineering education and professional settings to inform their thinking about engineering work. I assume there may be consequences when an individual's engineering practice represents a significant deviation from dominant culture of the engineering communities in which they are working; they feel a diminished sense of belonging to the field, or not identify as or be recognized as a full or legitimate participant within that engineering community. It is not my goal, however, to trace the impact of sense of belonging on persistence. Rather, I begin with the task of understanding the role of a variety of experiences in shaping individuals' engineering practice, as well as their understandings of engineering as a field and their place within it.

# Chapter 3: Methods

Informed by the conceptual perspectives described above that emphasize linkages between culture and activity, I aim to advance an understanding of the ways individuals' experiences within particular engineering contexts, as well as the life experiences they bring to those contexts, inform their engineering practice and their perceptions about the field of engineering and their place within it. I explored these foci by highlighting individuals' perceptions about the emphases of the educational and professional engineering contexts in which they engaged and their approaches to solving complex problems, which ostensibly require attention to varied elements of an engineering problem, both technical and non-technical. Specifically, I asked the following questions:

RQ1: What engineering practices do participants perceive to be most and least emphasized in the engineering contexts in which they engage?

RQ2: How do these emphasized practices align with those practices and values participants personally consider to be most important?

RQ3: What types of factors do engineers most commonly attend to in addressing complex engineering problems?

RQ4: What educational, professional, and personal experiences do engineers cite as influential in their consideration of various factors when solving engineering problems?

RQ5: How do engineers negotiate their personal values and prioritized aspects of engineering within the engineering contexts in which they engage and how does this relate to their practice and perceptions of engineering?

My research is supported by an NSF-funded study (Award number: EEC-1733665) focused on defining and assessing systems thinking expertise and identifying experiences that contribute to this expertise.

I collected data from engineers and engineering students with varying educational and professional experiences. Data collection was comprised of two main components: a) an interview with 46 participants about their past experience solving a particular complex problem and their experiences in engineering more broadly and b) an interview with a card sort component designed to elicit participants' perspectives on the engineering practices emphasized in their academic and professional communities, as well as the practices they personally identify as key in solving complex problems in their fields. Table 1 provides a summary of the research goals, participants, and design of these two components of my research design.

**Table 1: Summary of Goals, Sample, and Method by Study Component**

| **Study Component** | **Research Goals** | **Participants/Sample** | **Method** |
|---|---|---|---|
| First Interview | • Learn about participants' past professional and educational experiences<br>• Elicit a detailed account of their experience solving a complex systems problem and how that experience connects to other professional/educational experiences<br>• Understand participants' perceptions of engineering work and skills for addressing complex problems in their organization and field | • 46 Participants, Selection Criteria:<br>○ Recent work on project requiring systems thinking<br>○ Diversity Criteria:<br>○ Level of experience<br>○ Engineering Discipline<br>○ Gender<br>○ Race/Ethnicity<br>○ University<br>○ Nature of past engineering experience<br>○ Nature of employment | • Semi-structured interviews<br>• 60-90 minutes duration<br>• Ask participants to list or visually depict the problem they worked on and factors considered in solving it |
| Card Sort Interview | • Understand participants' perspectives on the qualities of an engineer most and least emphasized in their academic and professional experiences, as well as those they personally identify as key for | • 18 participants selected from original 46 participants, selected a diverse sample based on responses to first interview and selection criteria used for first interviews | • Semi-structured interviews<br>• Card sort activity in which participants are asked to select, from a deck of 26cards on which are listed possible qualities of |

| | | | |
|---|---|---|---|
| | solving complex engineering problems<br>• Explore alignment between academic/ professional experiences and what aspects of engineering work individuals prioritize | | an engineer, those view as most valued and devalued in their professional and academic experiences, as well as those they personally prioritize |

**Methodology**

I approached this study from a social constructivist perspective, assuming that knowledge is socially situated and constructed through interaction with others in a particular social context. This perspective aligns with my conceptual framing, drawing on the work of Holland et al. (1998) and Holland and Lave (2001; 2009), whose work builds on that of Leontiev, Vygotsky, Bakhtin, and Mead, among others. The epistemological affordances of these conceptual perspectives guided the framing of my research questions and the data collection and analysis approaches I used to answer them by focusing on understanding how individuals' engineering practice (specifically, how they approached a complex problem) was shaped by their experiences of/in particular social contexts, inherent in which are contextually-specific knowledge and values, as well as how they understood their own place within these contexts and the field of engineering more broadly. The social constructivist perspective that informed my work, as well as the specific conceptual lenses I employed, required that I explore issues of power and conflict as related to differently valued forms of engineering work, specifically, how implicit and explicit assumptions about what constitutes engineering work in different engineering contexts may serve to reproduce the status quo in terms of what engineering work entails and who is recognized as an engineer. Because views of engineering work and engineering self-concepts are socially constructed, they are subject to negotiation between actors with varying levels of status (including on the basis of social forces such as ideas about race and gender) in given contexts and can serve as a basis by which status or recognition is conferred. Further, they are influenced by the larger cultural context of common beliefs about engineering work. An emphasis on conflict is manifest in Holland and Lave's (2009) work through their characterization of local contentious practice and the ways larger social forces are inscribed in locally situated interactions between diverse actors.

The methods I employed to address my research question followed from this epistemological and conceptual framing. This sub-section provides an overview of the ways my conceptual framing informed my methods. A more detailed description of my methods, including participant selection, data collection logistics, instrument development, data management, analysis, and trustworthiness of data is provided in later sub-sections.

Semi-structured Interview: The first phase of my study, an interview exploring participants' experiences solving a complex engineering problem, allowed me to understand their approaches to solving complex engineering problems grounded in the context of a particular social world. This approach reflects the conceptualization of individual meaning-making as locally constructed within particular cultural contexts and as informing the actions of individuals engaging in those contexts. Focusing on individuals' experiences solving problems in a real-life context allowed me to understand participants' engineering practice within their educational and workplace contexts and how it was informed or constrained by the values or norms within those particular contexts. I asked participants to reflect on their decision-making process and rationales for their decisions in approaching a given engineering problem, and in keeping with a critical perspective, invited a conversation about any conflicts or tensions that arose throughout this problem-solving process, including if participants would have made other choices if free to do so. This approach was aligned with my goal of understanding how dominant cultural values may shape engineering work and if aspects of an engineering solution that were personally important to participants were not valued or attended to by others who shared or oversaw their decision-making process. For greater insight into participants' perceptions of their academic or work environment, I also asked them to reflect on the extent to which the problem-solving experience they describe is typical of that setting, of their particular field, and of engineering as a whole. Because my conceptual framing emphasizes particular social contexts as situated within a larger ecosystem, it was important understand how participants understood and situated their experiences within this broader social context.

Card Sort Activity: The second element of my study, a card sort interview, focused on developing an understanding of participants' perceptions of the cultural values of their various past and present engineering communities as related to engineering practice and how these aligned with their own values and prioritized practices. The theories I draw on in my conceptual framing suggest individuals participate in multiple educational and professional engineering communities that have different understandings of valued, dominant forms of engineering practice. How different practices are valued and recognized in a given context may motivate the individuals acting in that context, informing their understanding of what constitutes (valued) engineering work. Individuals' experiences both within and external to engineering contribute to their history-in-person that they bring with them into new contexts and may provide a broader repertoire of experiences and values upon which to draw when conducting engineering work in a particular context, potentially expanding the forms of engineering practice performed (if not recognized or valued) in that context. An understanding of the forms of engineering practice (un)recognized and (de)valued in participants' engineering education and work is essential to be able to compare and begin to connect these valued practices and those participants demonstrate in the first two study phases as they address a complex systems problem. Asking participants to also identify the forms of engineering practice they personally value also provided entrée into a conversation about the conflicts they experienced in instances when their own values did not align with what they perceived to be the dominant values of a given engineering context and how that shaped their perceptions and practice of engineering.

Analysis: My three findings chapters reflect different analytical approaches, with a collective goal of characterizing the valued forms of engineering practice in the different contexts represented in the study; personal, professional, or academic experiences that facilitated attention to various aspects of engineering work; and how these align with participants' practice of engineering work and their perceptions of engineering and their place within it. While each chapter has a distinct analytical focus, I aim for them to collectively provide insight into the ways individuals' experiences in various engineering/non-engineering contexts shaped their understandings of the field and their roles within it and the elements they attend to in a complex engineering project as a means to explore the relationship between engineering culture(s) and practice.

This emphasis on conceptual understanding motivates my analysis in all three chapters and, while my first two findings chapters have a more descriptive focus, these findings provide necessary grounding for a bigger picture conceptual understanding of the ways local cultures, identities, and practice are intertwined. My conceptual framing, particularly Holland and Lave's (2001; 2009) description of contentious local practice and the inherent power struggles in collectively negotiating meaning, guided me to be sensitive to instances of conflict that might shed light on the ways dominant cultural values restrict the forms of engineering practice that are recognized and valued in a given context and how, if at all, participants' practice can deviate from these normative forms of practice. In Chapter 7, I integrate findings drawn from my findings chapters to discuss the larger conceptual implications. My data collection and analysis strategies are described in greater detail in the remainder of this section.

## Participants and Recruitment

### *Selection Criteria and Participant Characteristics*

During the first phase of the study from which my data are drawn, I recruited 46 engineering students and professionals with a range of experiences. In addition, I recruited 18 of these 46 individuals to participate in second phase interviews. Because my research goal is to understand how different professional, educational, and life experiences relate to the elements they choose to attend to in solving a complex engineering problem, a purposive sampling approach was used to ensure the sample of participants was varied both in the degree of their engineering experience but also in the nature of their experiences, engineering-related and otherwise. This purposive sampling approach is consistent with recommendations for an exploratory interview study (Seidman, 2006; Small, 2009).  The selection criteria guided participant recruitment and selection are described in detail in the section below. Potential participants were asked to complete a brief questionnaire, with several questions related to their backgrounds and engineering experiences to aid in the participant selection process.

The first criterion for all participants in this study was that they must have had some kind of experience solving a complex open-ended problem, which they could draw on in our first interview. This criterion is defined as experience working on an open-ended complex project that had multiple potential solutions and for which there were multiple people with different forms of expertise working on multiple facets or components of the project. This definition, used in recruitment contacts, was intentionally broad to ensure engineers with a range of expertise may be able to meet this criterion. Possible experiences that fit this description included semester long course projects in an introduction to engineering design class or professional work designing vehicles or technology systems. Given the complexity of some engineering projects, I did not require participants had seen the project through to completion at the time of the interview, but rather selected participants who had worked on their projects for an extended period of time so that they were able to speak to their experiences navigating the process of generating and converging on potential solutions.

In addition, I considered a number of criteria to help ensure a diverse range of perspectives on and approaches to systems thinking are represented in my sample. These criteria included participants' level of educational/work experience, engineering discipline, nature of past engineering experience, nature of employment, and sociodemographic characteristics. These criteria are explained in further detail below:

- ***Level of experience***: While experience does not necessarily ensure attention to a broader range of facets of engineering work, by recruiting individuals with varying degrees of educational and career experience, I aimed to diversify the perspectives and approaches to addressing complex engineering problems represented by individuals in this study. Participants included 10 early undergraduate students (Freshmen and Sophomores), nine advanced undergraduate students (Juniors and Seniors), nine graduate students without work experience, five graduate students with prior work experience (four early career professionals and one advanced professional who went back for PhDs), three early career professionals not currently enrolled in graduate school at the time of our interview, and 10 advanced career engineering professionals.
- ***Engineering Discipline:*** Because the types of qualities, skills, knowledge, and problem-solving strategies emphasized might vary by engineering discipline, participants who

studied and/or worked in a variety of engineering fields (e.g., mechanical engineering, civil engineering, chemical engineering) were recruited. Participants in my study came from a total of 19 different engineering sub-fields or disciplines.

- ***Nature of past engineering experience***: Even within disciplines, engineering students and professionals are likely to have participated in different types of experiences or projects. Given my focus on the extent to which participants attend to the technical and social elements of a complex problem, and academic, co-curricular, professional, or volunteer experiences that are explicitly socially-oriented may make individuals more inclined to be aware of and attend to sociocultural elements of a complex problem. Thus, my sample included participants who did and did not have this type of engineering experience. Within my study, examples of engineers with these types of experience included those with experiences in socially- and sustainability-minded design teams or research settings or engineering education-oriented professional work experience.
- ***Sociodemographic Characteristics:*** Literature suggests that women and/or racially minoritized students are more likely to be drawn to more socially engaged engineering work (Litchfield & Javernick-Will, 2015; Swan, Paterson, & Bielefeldt, 2014). However, these same students also often report feeling a disconnect between this socially-oriented engineering work and the larger field of engineering (Diekman et al., 2011; Gregory & Hill, 2000; Smith et al., 2014). The extent to which individuals attend to the sociocultural versus the technical components of a complex problem, as well as the experiences that shape that, are at the core of this study. Thus, it was critical that this study included participants who were diverse in terms of gender and racial/ethnic backgrounds. One-third (15) of my participants were women, compared to the 20.9%

who earned bachelor's degrees in the field in 2016 or 15.6% of the engineering workforce who are women nationally (NSF, NCES, 2019). Fifty percent of my sample identified as White, 24% as Asian, 13% as Latinx or Hispanic, 9% African American, and 2% each as Multi-racial and North African. Nationally, of the domestic 2016 bachelor's degree recipients in engineering, 59.3% were white, 10.8 percent were Asian, 10.4 percent were Latinx or Hispanic, 3.9 were African American, and a fraction of a percent were American Indian or Alaska Natives or Native Hawaiian or Pacific Islander.

- ***University (for current students):*** The sample of current students included students from UM Ann Arbor and UM Dearborn. These two institutions, though both part of the University of Michigan system, represent two very different educational environments demographically and are likely to include students with different educational and life experiences. U-M Ann Arbor is a selective public research university characterized as having very high research activity. As of Fall 2015, U-M Ann Arbor had a total enrollment of 43,651 students, about 65 percent of which are undergraduates. In contrast, U-M Dearborn is a smaller, less selective regional public university with a total Fall 2015 enrollment of 9,308, more than three-quarters of which were undergraduate students. A smaller proportion of U-M Ann Arbor's students are Michigan residents (56%, compared to 93% at U-M Dearborn) and U-M Ann Arbor also enrolls a substantially smaller proportion of underrepresented minority students than U-M Dearborn (12.6 and 26 percent, respectively). Of the 19 undergraduate students included in the study, seven were from U-M Dearborn, as was one graduate student.

Of the 46 participants in the first phase of the study, a smaller subset of 18 were recruited for follow up interviews. In recruiting participants for the second phase of the study, I considered many of the same diversity criteria. However, because one aspect of these second phase interviews included reflection on educational experiences, I disproportionately sampled participants who were currently enrolled as engineering undergraduate or graduate students or who had sufficiently recent educational experiences that they would be able to recall them in some detail. Table 2 below, provides a summary of participant characteristics.

**Table 2: Participant Characteristics**

| Pseudonym | Engineering Field | Experience Type | Gender | Race/ Ethnicity | In Phase 2 |
|---|---|---|---|---|---|
| Saba | Computer Science Engineering | Early Undergrad | Woman | Asian | Yes |
| Galen | Aerospace Engineering | Early Undergrad | Man | White | No |
| Landon | Engineering – Unspecified | Early Undergrad | Man | Latinx/ Hispanic | No |
| Emerson | Biomedical Engineering | Early Undergrad | Man | White | Yes |
| Zane | Industrial and Operations Engineering/ Computer Science Engineering | Early Undergrad | Man | White | No |
| Preston | Engineering – Unspecified | Early Undergrad | Man | White | No |
| Adam | Mechanical Engineering | Early Undergrad | Man | White | No |
| Paris | Engineering – Unspecified | Early Undergrad | Woman | Asian | Yes |
| David | Electrical Engineering | Early Undergrad | Man | Asian | No |
| Maya | Engineering – Unspecified | Early Undergrad | Woman | Asian | No |
| Nelson | Electrical Engineering | Advanced Undergrad | Man | White | Yes |
| Noel | Industrial and Operations Engineering | Advanced Undergrad | Man | White | No |
| Karsen | Automotive Engineering | Advanced Undergrad | Man | Asian | No |
| Effie | Biomedical Engineering | Advanced Undergrad | Woman | White | No |
| Gail | Industrial and Operations Engineering | Advanced Undergrad | Woman | Multi-racial | No |
| Brody | Engineering – Unspecified | Advanced Undergrad | Man | White | No |
| Tyler | Robotics Engineering | Advanced Undergrad | Man | White | Yes |
| Kamila | Mechanical Engineering | Advanced Undergrad | Woman | White | No |
| Samir | Computer Engineering | Advanced Undergrad | Man | Asian | No |
| Jalen | Mechanical Engineering | Grad Student | Man | Asian | No |

| | | | | | |
|---|---|---|---|---|---|
| Raelyn | Materials Science Engineering | Grad Student | Woman | White | Yes |
| Yori | Mechanical Engineering | Grad Student | Woman | Asian | No |
| Eric | Environmental Engineering | Grad Student | Man | Latinx/ Hispanic | Yes |
| Edna | Space Engineering | Grad Student | Woman | White | No |
| Dominic | Biomedical Engineering | Grad Student | Man | Latinx/ Hispanic | Yes |
| Marjorie | Computer Science Engineering | Grad Student | Woman | Asian | Yes |
| Orlando | Applied Physics / Engineering | Grad Student | Man | Latinx/ Hispanic | Yes |
| Germain | Energy Systems Engineering | Grad Student | Man | White | No |
| Sebastian | Computer Science Engineering | Grad/Early Career | Man | Asian | No |
| Alvin | Industrial and Operations Engineering | Grad/Early Career | Man | White | Yes |
| Milton | Design / Industrial Operations Engineering | Grad/Early Career | Man | African American | Yes |
| Diego | Industrial and Operations Engineering | Grad/Early Career | Man | Latinx/ Hispanic | Yes |
| Jocelyn | Industrial and Operations Engineering | Grad/Advanced Professional | Woman | Asian | Yes |
| Leah | Mechanical Engineering | Early Career Professional | Woman | White | Yes |
| Kara | Design / Mechanical Engineering | Early Career Professional | Woman | White | Yes |
| Bowen | Biomedical Engineering | Early Career Professional | Man | White | Yes |
| Candace | Energy Systems Engineering | Advanced Professional | Woman | African American | No |
| Roland | Mechanical Engineering | Advanced Professional | Man | African American | No |
| Jasper | Mechanical Engineering | Advanced Professional | Man | African American | No |
| Norman | Structural / Civil Engineering | Advanced Professional | Man | North African | No |
| Stewart | Structural / Civil Engineering | Advanced Professional | Man | White | No |
| Alek | Engineering – Unspecified | Advanced Professional | Man | White | Yes |
| Alisha | Biomedical Engineering | Advanced Professional | Woman | White | No |
| Byron | Engineering Management | Advanced Professional | Man | White | No |
| Julian | Information Systems Engineering | Advanced Professional | Man | Latinx/ Hispanic | No |
| Felix | Climate and Space Engineering | Advanced Professional | Man | White | No |

*Note: Early Career Undergrad reflects students in their 1st or 2nd year of study, while Advanced Undergrads are in year 3 or above; Early career includes those with fewer than 10 years of professional work experience with Advanced Professional reflecting those with 10 or more years of professional work experience*

*First Phase Recruitment*

Participants were recruited via email through several means. At U-M Ann Arbor, I identified and recruited students who had enrolled in several sections of an introductory engineering course the previous semester in sections that ranged in disciplinary focus and the extent to which contextual aspects of engineering were emphasized in the course description. In addition, Dr. Daly, a Principal Investigator on the grant funding this work and a faculty member in Mechanical Engineering at U-M Ann Arbor, assisted with contacting students affiliated with a number of engineering teams, including technical design teams and engineering project teams with focuses on medicine, international impact, and sustainability, for recruitment. Dr. Daly and several other faculty contacts in the College of Engineering at U-M also helped share my recruitment emails with graduate student researchers in several engineering labs. In addition, I contacted leads of several engineering graduate student organizations and asked them to share recruitment materials with their members. At U-M Dearborn, Dr. DeLean Tolbert, an advisory board member for the grant and an engineering faculty member there, helped share recruitment materials with students who had recently enrolled in an introductory engineering course there as well as students involved in several automotive engineering project teams.

To recruit professionals, I relied on a range of personal and professional contacts willing to share study information with engineers in their networks who were working in the Southeast Michigan region. In several instances, participants offered to connect me with others in their network, which I accepted, staying mindful of the recruitment diversity criteria in terms of participants' engineering field and personal/professional background. All interested participants were asked to fill out a brief informational questionnaire via Qualtrics survey software. These questionnaires allowed for screening based on the selection criteria described above and provided useful context for the interviews. A copy of the screening questionnaire is located in Appendix A. Participants received Mastercard gift cards for their participation. Those who were currently enrolled as undergraduate or graduate students received $25 for each of the two phases of the study while professional engineers were given $50 for each phase.

*Second Phase Recruitment*

Participants in the card sort interview that was also part of the second study phase were recruited from the pool of 46 participants described above. Participants indicated in the informed consent given to them in the first interview if they were willing to be contacted for subsequent research, and I reached out only to those who responded in the affirmative. Participants were contacted via email, following up on our original correspondence. A total of 18 individuals participated in this data collection effort. Participants in this phase received a second Mastercard gift card for their participation, with currently enrolled students again receiving $25 and working professionals receiving $50.

**Data Collection Protocols and Procedure**

As described in the Methodology subsection, the two elements of my data collection plan were designed to provide different types of information. The first element, interviews with participants with varied professional, educational, and life experiences, elicited information about participants' experiences in engineering as well as an example of the approaches participants used to solve an engineering systems problem in a real-world context. The second element, an interview aided by a card sort activity, provided an understanding of the engineering practices emphasized in participants' educational and professional contexts, as well as the alignment of these practices with those the participants personally felt were most important in solving a complex engineering problem. This section provides more detail about the content and conduct of each of these study elements.

*First Interview*

**Protocol Development and Content.** The objectives of the NSF grant that funded this research, as well as this study, informed the development of the interview protocol. Specifically, the interview was designed to provide an understanding of participants' engineering education and professional experiences and elicit rich description of a particular experience they had in solving a complex engineering problem. The project research team, consisting of myself and the two study investigators, met regularly to discuss and refine the first several drafts of the protocol for alignment with our study objectives and for clarity. An informal focus group of eight undergraduate and graduate engineering students provided feedback on the clarity and content of the protocol during this process. The members of the grant project advisory board, which consists of five faculty members with expertise in engineering education research, social science research, and engineering systems thinking, provided feedback on this revised protocol. Finally, I pilot tested the interview protocol with seven engineers and engineering students with different levels of experience, to gain additional feedback on the clarity and focus of the interview questions. Based on feedback in these pilot interviews, I made several changes to the interview protocol. These changes included dropping several questions that were eliciting redundant information in order to shorten the interview, rearranging several questions for better interview flow, and altering the language of the question asking about participants' experiences solving a complex problem to account for a greater range of project types and project outcomes. These multiple phases of iteration on the interview protocol were intended to enhance the validity of the interview instrument and check for questions that may be leading, biased, or unclear (Creswell, 1994; Patton, 2002).

The primary focus of the first interview was eliciting detailed information about a specific experience that participants had solving a complex engineering problem and their approach used to address that problem. Participants were asked to describe the problem in detail, how work on the project was organized, major decisions that had to be made in addressing the problem, the types of factors (i.e., requirements, constraints, inputs) considered, and any conflicts or tradeoffs that were a part of the process. The protocol also includes questions about the skills and knowledge participants feel are important in solving complex engineering problems, as well how their typical approach and priorities in addressing such problems compares to those of other engineers. Data from this interview provided insight into the aspects of engineering participants attended to in practice, their personal experiences or contextual influences that shaped what they attended to, their trajectories into engineering and feelings about their work, and insight into their approaches and priorities compared to other engineers. Full text of the interview protocol is available in Appendix B.

This initial interview was grounded in participants' lived experiences to facilitate an understanding of their approaches to solving complex problems. Relying on concrete experiences likely facilitates deep reflection, rich detail, and greater accuracy, in contrast to general questions about systems thinking which may only yield vague or superficial responses that may not reflect participants' experiences in practice (Rubin & Rubin, 2011; Weiss, 1994). Similar approaches have been used in engineering education previously to understand particular problem-solving approaches or specific details of participants' academic or professional experiences (e.g., Atman et al., 2007; Cross & Cross, 1998).

**Interview Logistics.** The first interviews ranged in duration between 40 and 96 minutes. I met participants in person in mutually convenient semi-public locations of their choice, including a designated interview room, conference rooms, their office, and the public library. Interviews were digitally recorded and later transcribed verbatim. Participants were asked to sign an informed consent form before beginning the interview. I personally conducted all 46 interviews, using the semi-structured interview protocol described above. In addition to answering questions about their perspectives and experiences related to solving complex systems problems, participants were asked to list or visually depict the factors they considered in solving a problem as a means to prompt reflection. Scanned copies of all drawings produced during the interview and other data files associated with these interviews are stored digitally in a secure folder.

*Second Interview*

**Card Sort Interview Content and Administration.** Data collection consisted of an interview grounded in a card sort activity in which I asked participants to identify and talk me through their ordering of different types of engineering practices in three rounds of the activity. Participants were given a deck of 26 index cards with a different engineering practice listed on each card. See Figure 2. These practices were generated from a systematic review of common and desirable qualities and skills of engineers (Passow & Passow, 2017) and feedback from conversations with undergraduate and graduate engineering students, as well as our advisory board. We sought feedback on the extent to which the listed practices align with the practices emphasized in individuals’ own educational and professional experiences. Finally, a research assistant reviewed participants’ responses to a question from the prior study phase about the types of engineering skills they felt were important to identify any commonly-cited skills or practices not already included on our list. In addition to seeking feedback to generate and refine the list, I elicited feedback on the clarity of items from a group undergraduate and graduate engineers and then conducted pilot interviews with an additional seven students to ensure clarity and comprehensiveness. Based on feedback from these conversations and pilot interviews, I made several revisions to the activity, including adding several practices, clarifying detail to cards, and dropping practices perceived to be redundant. In addition to the list of practices provided to participants to select from, participants were given the opportunity to identify and discuss additional practices that were important in a given engineering community but that were not included on our list. The engineering practices included in the card sort activity represent a range practices related to research, technical ability, communication, design, and social/contextual awareness. All practices were assigned a randomly generated letter from A to Z to facilitate quick written recording of practices named during the interview. The cards were given to participants as a randomly shuffled set.

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 2: List of practices used in card sort interview activity

During the interviews, I asked participants about the practices they perceived to be most and least valued in two engineering practices in which they participated. All participants were asked to reflect on the context they described in their first phase interview. For undergraduate engineers, this could have been a project-based engineering course, cocurricular project team, or internship experience, while graduate students often discussed the academic context associated with a research project of theirs and professional engineers often described their current workplace. In addition, participants were asked about an additional context – for undergraduates, I asked them to reflect on their undergraduate engineering courses generally. Graduate students and professional engineers were asked about their undergraduate education experiences. The one exception to this was current graduate engineers with extensive professional experience, who were asked about their professional and graduate study experiences, and then asked to reflect on how their undergraduate experiences compared. A full list of the two contexts discussed by each participant is included in Table 3.

**Table 3: Engineering Contexts Discussed in Card Sort Interviews**

| Participant | Context 1 | Context 2 |
|---|---|---|
| Saba | Undergrad – Overall | Undergrad - Intro Course |
| Emerson | Undergrad – Overall | Undergrad - Intro Course |
| Nelson | Undergrad – Overall | Undergrad - Project Team |
| Paris | Undergrad – Overall | N/A |
| Raelyn | Masters - Overall | Work - Computer Industry |
| Alvin | PhD - Overall | Work - Medical Industry |
| Eric | PhD - Overall | Undergrad - Overall |
| Dominic | PhD - Overall | Undergrad - Overall |

| | | |
|---|---|---|
| Marjorie | PhD - Overall | Undergrad - Overall |
| Orlando | PhD - Overall | Undergrad - Overall |
| Tyler | Undergrad - Overall | Undergrad - Project Team |
| Diego | Work - Engineering Education | PhD - Overall |
| Jocelyn | Work - Military | PhD - Overall |
| Leah | Work - Tooling Industry | Undergrad - Overall |
| Alek | Work - Medical Startup | Undergrad - Overall |
| Milton | PhD - Overall | Work - Varied |
| Kara | Work - Auto Industry | Undergrad - Overall |
| Bowen | Work - Medical Startup | PhD - Overall |

For each context discussed, I first asked participants to sort through the deck to identify the three to five practices (though some participants selected more) that they perceived to be most emphasized or valued in that context, regardless of how personally important they perceived them to be. I then asked them about the practices they perceived to be least valued or emphasized and prompted as necessary for their reasoning or experiences that contributed to these sorts. I asked follow up questions including the following:

- Were there any other practices or skills not included in the deck that you think were really valued in that setting?
- How do you think those emphasized practices aligned with what you personally felt were the most important? (Are there things that are over- or under-emphasized?)
- *If student:* 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?
- *If grad student or professional*: How do you think your earlier [educational/work] experiences compare to what you just described, in terms of the practices emphasized?

Finally, after asking the above questions for two engineering contexts, I asked participants to do a final sort to select the five practices that they personally considered to be most important for solving a complex problem in their field and why. I then asked them to reflect on how well the practices they personally prioritize aligned with their educational/professional experiences, and if they felt their personal skills and perspectives were generally recognized and valued in the engineering contexts in which they had participated and how so.

The card sort interview described above was conducted as the second part of a two-part follow up interview with a subset of participants from the first phase of the study. The first portion of the interview 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 Management Plan**

Participant data were collected following IRB approved procedures. All data storage and sharing was done in a manner consistent with IRB procedures as well as the University of Michigan's Safe Computing guidelines. Original digital data files are kept in a secure, password protected folder on UM's internal Box cloud storage platform. These audio files were transcribed and individual identifiers are omitted from any reporting of the data. Participant names have been replaced with pseudonyms, allowing for analysis by participant while still maintaining participant confidentiality. Hard copies of documents, such as participant documents from the first interview and informed consent forms, will be maintained in a locked file cabinet in a locked laboratory for the duration of the study. For the duration of the study, which is inclusive of analyses outlined in the grant funding this work, data will be accessible to myself, project investigators, and any research assistants. I will ensure that no identifying information, implicit or explicit, will be included in any publicly available documents.

**Analysis**

My analysis based on these two data sources was organized around specific research goals, reflected in the focus of my three findings chapters. In the sections below, I describe my analyses by chapter, specifying which data were used in each. Prior to these analyses, I took several steps to prepare and understand my data. As mentioned previously, recordings of all interviews were sent to a third-party service for transcription. I reviewed each transcript for accuracy and to re-familiarize myself with the content. In addition, for all interviews included in the first phase of the study, I created a descriptive codebook, focused on capturing passages that addressed various questions in my interview protocol and providing a more detailed categorization of several topics of interest to the present analyses and those of the larger study this data is a part of. Codes included both a priori codes, based on expected responses from the interview protocol and relevant literature, as well as inductive codes that I identified based on review of the interview data (Miles, Huberman & Saldana, 2013; Patton, 2002). I used a subset of 10 transcripts to develop the first draft of the codebook, coding each of these transcripts in their entirety. After this, I trained two student coders, one undergraduate student in engineering and master's student in higher education, to code the remaining codes. The coders consulted with each other and myself in weekly meetings to refine the codebook, clarify their understanding of various codes, and ensure consistent coding. The two coders worked together, coding the same transcripts for several weeks, until we were confident their coding was well-aligned, and then completed the remaining coding independently, meeting with me regularly to discuss any questions. After all transcripts were coded and finalized, transcripts and their codes were entered into NVivo 12, qualitative analysis software that facilitates greater organization, search, and analysis functions. While the codebook is primarily descriptive and serves the goals of both my dissertation and the larger study, I describe its use in greater detail when relevant in the sections below. To ensure I had a deep understanding of my data and to identify emergent trends, I created a number of preliminary summary tables of my coded data and compiled summaries and supporting data relevant to my research questions. In addition, I wrote brief analytic notes throughout the process to understand emergent patterns and explore connections to literature and theory (Emerson, Fretz, & Shaw, 2011; Jones, Torres, Arminio, 2013).

*Chapter 4 Data Analysis*

In Chapter 4, I explored the engineering practices participants perceived to be the most and least emphasized in the engineering contexts in which they participated and how well these emphasized practices aligned with participants' personal values and priorities. To address these questions, I drew exclusively on data from the card sort interviews with the subset of 18 participants included in both study phases. Analysis for this study took place in two parts: first summarizing trends in the practices emphasized across different contexts and for participants overall and second by characterizing different categories of participant responses based on the extent to which they personally prioritize social and contextual aspects of engineering work and the degree of dissonance they perceive between their personal emphases and those of the engineering environments in which they engage. The first part of this analysis 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.

The findings presented in Chapter 4 summarize different categories of participant responses on the basis of personal emphasis of social and contextual aspects of engineering and their expressed dissonance between their personal values and their perceived emphases of the engineering contexts in which they engage. I began these analyses by reviewing each transcript several times, summarizing all statements participants made about the aspects of engineering they personally valued or prioritized (even if these were not among those mentioned as their top practices in the card sort task), as well as any instances in which the participant reflected on the degree of agreement with the emphases of the engineering contexts in which they have participated or the field of engineering more generally. I compiled these summaries and all supporting excerpts into a single document. I shared these summaries with two members of the research team, and we collectively discussed emergent patterns that suggested participants varied both in their valuing of social and contextual aspects of engineering work and the degree of conflict or dissonance they expressed related to the emphases of their engineering contexts. I then re-reviewed participant summaries and transcripts to begin to categorize them on the basis of these two dimensions. Initially, I sorted participants into four quadrants: high emphasis on social/contextual aspects and a high degree of dissonance, high emphasis on social/contextual aspects and a low degree of dissonance, low emphasis on social/contextual aspects and a high degree of dissonance, and low emphasis on social/contextual aspects and a low degree of dissonance. However, very few participants fell into the high/low and low/high categories so quadrants did not allow me to adequately capture the range in experiences between participants who expressed moderate degrees of emphasis or dissonance and those expressing very high or low degrees of emphasis or dissonance. After discussing these findings with my co-chairs, I elected to re-categorize participants into nine potential categories of high, medium, and low emphasis of social/contextual aspects of engineering work and high, medium, and low degrees of expressed dissonance.

The categorization of participants was determined relative to other participants and relied also on the following characterizations of social/contextual aspects of engineering work and dissonance. For the purposes of this study, I defined an emphasis on social and contextual aspects of engineering work to be those aspects relating to the cultural context in which engineering work is embedded, the potential human or societal impacts of engineering work, including future impacts of the work, ethical or moral considerations, and relationship dynamics between engineers and their team members, clients, or other potential stakeholders. The varying levels of this social/contextual emphasis manifested in a variety of ways between different participants; some discussed their personal emphasis on "people-centered" aspects of engineering, others discussed seeking personal and cultural understanding of stakeholders for a project, while others discussed the extent to which they did or did not feel it was important to consider human or societal impacts in engineering solutions.

I characterized dissonance based on participants' reflections on the extent to which they agreed with the aspects of engineering work most and least emphasized in the educational and professional contexts in which they engaged or in engineering more generally, how they felt their personal engineering priorities were represented in their training and work experience, or any other comments that suggested agreement or tension related to their educational or professional experiences. In addition, I reviewed participants' responses to the question about the extent to which they feel their skills and perspectives are recognized and valued in engineering, both as another opportunity to reflect on potential dissonance and also on the implications of this alignment for recognition in the field, consistent with Holland et al.'s (1998) suggestion that enacting recognized and valued forms of practice in a given context has implications for one's inclusion and recognition, both key in identity development.

*Chapter 5 Data Analysis*

In Chapter 5, my analysis is primarily descriptive and centers on the types of factors that engineers attend to in solving complex problems and the types of experiences they identified as influential in their consideration of these factors. All 46 participants' first-phase interviews are included in this analyses. I drew on data about participants' real-life experiences addressing a complex problem and their reflections on their experiences in engineering more broadly. The analysis is twofold: I identified and categorized the types of factors most and least commonly mentioned in participants' descriptions of their problem solving experiences and characterized the types of experiences participants identified as influential in their attention to these various factors.

To identify and categorize the types of factors participants described attending to in solving complex engineering projects, I ran queries of my coded interview data in NVivo 12 to identify the passages coded as instances of a participant accounting for a particular type of factor in their work and, after review of these passages, to identify counts of how many participants described attention to each factor type in their description of their experiences solving a complex engineering problem. The codebook included 14 distinct factor types, which were generated both deductively and inductively. Some factors were identified from literature informing the larger grant's definition of important factors in solving complex problems in engineering and beyond (e.g. Bahill & Gissing, 1998; Frank & Elata, 2004; Frank & Israel, 2000; Grohs, 2014; Hogan & Weathers, 2003; Senge, 1990); others were inductively derived from participants' descriptions of what they attended to in problem solving in our interviews. These factors, described in detail in Chapter 5, include attention to: technical details, team dynamics and staffing, material/financial resources, stakeholders, project timeline, manufacturability, interrelationships between components, provided specifications or requirements, cultural or social context, environmental impact, immediate context, political or economic context, future considerations, and history and prior solutions. Based on my review of the ways participants spoke about each of these definitions and my a priori definitions used for coding, I categorized these 14 factors into six main categories: contextual, internal coordination, technical, immediate conditions and constraints, stakeholders, and interrelationships between factors. These categories and my rationale for the grouping are described in detail in Chapter 5.

The primary analytical focus of Chapter 5 was capturing the types of experiences participants cited as influential in their attention to various types of factors. I ran a coding report using NVivo to identify all passages where participants mentioned any prior experiences in our interview. Then, I reviewed all passages and flagged any passages in which participants described a prior experience, whether academic, personal, or work-related, as influencing their attention to a particular factor type in solving an engineering problem. I compiled these instances into a spreadsheet, organized by participant, a reference number linking to the location in their interview, a brief summary of each experience, and the factor type informed by the experience. In instances where a participant named a particular experience as shaping their attention to multiple factors or aspects of an engineering problem, I counted each as a separate entry. I used this document to guide my discussion of the types of prior experiences participants had related to each factor type and develop a summary table, categorizing experience types into broad categories including classroom instruction, university project teams, internship experiences, professional work experiences, pre-college experiences, and experiences in one's personal life.

*Chapter 6 Data Analysis*

In Chapter 6, I drew on social practice theory to explore how engineers' personal histories and values and their participation in particular engineering contexts relate to their perceptions of engineering and their attention to different aspects of engineering in their own work. I employed a case study approach (Flyvberg, 2001; Miles, Huberman, & Saldana, 2013) to explore these phenomena in-depth and drew connections between what I observed in my data and the theories that inform my work (Holland et al., 1998; Holland & Lave 2001; 2009). I selected four cases to analyze based on analyses in Chapter 4, in which I categorized participants in part by the degree to which they personally valued or prioritized social and contextual aspects of engineering. I selected two participants from each end of the continuum, identifying one current student and one engineer with professional work experience from each. The engineers with professional work experience were able to reflect in depth on both their professional and educational experiences.

For each case, I drew on data from both interview phases. I read each participants' transcripts several times and took notes, adding to these summary data on each case from my analysis in Chapters 4 and 5. My use of social practice theory directed my attention to particular aspects of each case, which I describe in detail in Chapter 6. Broadly, my conceptual framing focused my analysis on characterizing the prior experiences and motivations each individual brings with them into engineering contexts, the values – implicit or explicit – of the particular engineering contexts in which they participate related to valued forms of engineering practice, the extent to which each individuals' personal values and practice of engineering work align with those dominant in their local engineering environments, and how these collectively shape participants' practices of engineering and their perceptions of their place within the field. In addition to describing each case and identifying theoretical linkages within each, I identified patterns across the four cases.

**Limitations**

There are several limitations to this study that have implications for the interpretation of study data and findings. First, given the range of experiences and professional and educational backgrounds, I am unable to make claims about the particular cultural values related to engineering work of any one particular engineering context. Similarly, this work draws on the experiences of 46 individuals and is not representative of all engineering contexts. Indeed, 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.

Relatedly, the number of participants and range of contexts in which they addressed engineering problems has implications for my interpretation of the aspects of engineering work participants attend to in their work. Participants only described their approach to solving complex problems in a single engineering context, which could differ substantially from how they approached other engineering problem-solving experiences in their careers or the problem solving experiences of engineers more broadly. The demands and nature of a particular project undeniably inform the aspects of engineering work participants engage in and are salient in their recollection of solving the problem. Thus, the particular factors participants reported accounting for in their work are not necessarily reflective of their typical problem solving approach. I relied on participants' reflection on how their experiences compared to other engineering projects and the aspects of engineering work they typically consider when addressing a complex problem for a more complete picture of what they foreground when engaging in engineering practice.

The study design and reliance on respondents' voluntary participation in both phases of interviews poses another potential validity threat. It is possible that individuals who agreed to participate may differ in substantial ways from those who did not agree to participate. While participants were recruited for the study on the grounds of their previous complex problem solving experiences, not their personal approaches to engineering nor feelings about the emphases of engineering educational and professional environments, individuals who agreed to participate may generally be more likely to reflect critically on their experiences. Conversely, it is possible that this selection approach meant that those who felt most confident in their engineering experiences and willing to classify their previous project experience as a complex engineering project were more likely to volunteer to participate. In addition, my recruitment of current engineering students and engineers eliminated from participation engineers no longer practicing or studying engineering. Individuals whose ideas about and practice of engineering differed from the forms of engineering practice most valued in a given engineering context may have opted out, or felt pressured out, of the field of engineering or at least the educational or professional community. In this way, my findings may be a conservative portrait of dissonances.

Finally, the primary focus of my study, the ways engineers' experiences in different contexts shape how they attend to different elements of a complex problem and how they perceive the field of engineering and their role within it, suggests a causal relationship. However, my data does not allow conclusive causal claims about these relationships. Rather, I use my data to highlight connections between these different elements, relying on participants' own accounts of the ways particular experiences shaped their engineering work and their thinking. In addition, I rely on my theoretical framing to direct my attention to relationships between the cultural values of particular practice, individual engineers' experiences of these contexts, their practice of engineering work, and how all of these are situated within the larger context of the field of engineering and the implications of these relationships.

**Trustworthiness of Data**

In light of these limitations and a broader desire to improve the trustworthiness of my data and interpretations, I engaged in a number of practices to help ensure the validity of my findings. My approach to facilitating greater trustworthiness in my findings is grounded in contemporary literature on validity in qualitative research (e.g., Irwin, 2008; Lichtman, 2006; Maxwell, 2013) that stress that the credibility of research findings is grounded in ones' analysis and the evidence provided to support the claims made, employing methods throughout the course of the study to help provide quality evidence. Thus, I took measures throughout my research process to help ensure my data was trustworthy, relevant to the questions I was asking, and of a high quality. I describe the measures taken related to my study design, participant selection and recruitment, and analysis.

Throughout the development of both interview protocols, I sought the guidance of experienced qualitative researchers and content experts as I generated interview questions. When developing the list of practices used in the card sort interviews, I relied both on existing literature about important engineering skills (e.g., Passow & Passow, 2017) as well as feedback from engineering undergraduate and graduate students to ensure the list was comprehensive and clearly defined. In addition, I pilot tested both protocols with engineering students from varied academic and personal backgrounds to help ensure my interview questions were clear and effective in eliciting rich information aligned with my research focus. Based on the results of several rounds of pilot interviews, I iterated on my interview protocols to revise or eliminate questions that were leading, biased, or unclear (Creswell, 1994; Patton, 2002). Both interview protocols were intended to elicit information about participants' specific concrete lived experiences, a strategy that helps ensure data more closely reflects participants actual experience and somewhat less influenced by the interviewing context (Rubin & Rubin, 2011; Weiss, 1994). In addition, by relying on two interviews, one based on reflection about a particular experience and a second interview using the card sort activity, I employed a partial strategy of methodological triangulation (Denzin, 1989). This strategy was intended contribute a deeper understanding of the ways individuals' experiences in engineering and non-engineering contexts informs the way they think about and conduct their engineering work.

Given the concerns described in my limitations section related to the characteristics of engineers who may self-select into a study on complex engineering problem solving and the aspects of their experiences and engineering problem solving approaches they consider to be relevant to share, I took several measures related to participant recruitment and interview design. First, I employed a screening survey in which participants provided basic background information and the nature of their past engineering project. This helped ensure I was able to include participants from a wide range of engineering contexts, with the assumption that they were likely to have varied experiences as well as varied approaches to approaching complex problems in engineering. Additionally, this screening step allowed me prioritize recruiting a demographically diverse sample, including women and racially/ethnically minoritized students who research suggests often feel alienated from the field (Baker, Tancred, & Whitesides, 2002; Gardner, 2008; Ong, Wright, Espinosa, & Orfield 2011; Tonso, 2014).

In the interviews themselves, I included language and prompts intended to encourage participants to share a wide range of experiences and engineering approaches, including those that were not common or highly valued within many engineering spaces. In addition, I explicitly invited participants to talk about any differences or conflicts between their own approach to solving a complex engineering problem and the types of engineering practice emphasized in their communities. Finally, the questions in the card sort activity about those elements of engineering practice that have not been highly valued in participants' engineering communities and an invitation to share their opinions on the practices that were emphasized in various engineering contexts were intended to provide an additional opportunity for participants to describe any potential disconnects between their own ideas of engineering work and those of their engineering communities.

Throughout my data analysis process, I engaged in a number of activities intended to facilitate critical reflection on my data, check my own interpretations, reflect on connections to theory, and promote greater trustworthiness of my data. In the initial coding of data, which was primarily descriptive, I relied on multiple trained coders, in regular communication with one another and with myself, to ensure consistency in the use of codes and thoroughness of the codebook. Throughout my study, I reviewed and reflected on the data multiple times, playing with different ways to organize and group the data. I created a number of initial summary tables to identify patterns in my coded data (Maxwell, 2013)  and compiled summaries and supporting data related to my various research questions. In addition, I wrote brief analytic notes in effort to distill my data, identify emergent patterns, and explore connections to literature and theory (Emerson, et al., 2011; Jones, et al. 2013). To check the plausibility of my interpretations and elicit other potential perspectives, I shared my initial findings and debriefed regularly with my dissertation co-chairs throughout the course of the study. In addition to inviting the interpretation of other researchers, I also sought discrepant evidence, working to be mindful of the full range of participant experiences, particularly those whose experiences ran counter to the predominant themes of my study (Maxwell, 2013). When interpreting and presenting my findings, I aimed to present rich detail to support my claims (Lichtman, 2007, Maxwell, 2013). Ultimately, I aim to provide sufficient detail and transparency to allow to reader to understand the basis for the claims I make and asses for themselves my conclusions.

# Chapter 4: Dominant Forms of Engineering Practice and Alignment with Participants' Values

In order to better understand the well-documented underemphasis on social and contextual aspects of engineering work and how emphasized aspects of engineering work are experienced by engineering students and practitioners, in this chapter I explore the practices predominant in the engineering contexts in which the participants engaged and how different participants perceived and reacted to these emphases. Specifically, I addressed the following research questions:

> RQ1: What engineering practices do participants perceive to be most and least emphasized in the engineering contexts in which they engage?
>
> RQ2: How do these emphasized practices align with those practices and values participants personally consider to be most important?

There is substantial prior literature that documents the extent to which technical aspects of engineering work are often prioritized over equally important (and indeed inextricably linked) social and contextual aspects of engineering. A number of scholars have documented engineering's grounding in positivist ideology, in which the ostensive ability of engineers to make value-neutral decisions, grounded only in technical considerations, has been a defining feature of the profession since the mid-nineteenth century and widely persists today (Carter, et al., 2019; Cech, 2013; Riley, 2008). Empirical work highlights an underemphasis on social, environmental, political, and cultural considerations in engineering courses (Lattuca et al., 2014), suggesting these positivist beliefs may underlie curricular decisions. Further, engineering students' ratings of the importance of a range of contextual public welfare beliefs actually declined over their course of an engineering degree program (Cech, 2014a; 2014b). These studies provide valuable insight into high-level patterns of an underemphasis on social and contextual aspects of engineering, and suggest that what is taught --and not taught -- in engineering programs may contribute to engineers' lower regard for the social and contextual consequences of engineering solutions. However, more work is needed to understand what this underemphasis looks like in different educational and work contexts and what that means to engineers with different value orientations.

In this chapter, I examined participants' perceptions of engineering practices in the educational and professional contexts they experienced, paying particular attention to their perceptions related to social and contextual engineering practices. Holland et al.'s (1998) conceptualization of figured worlds describes the ways various cultural contexts, such as an engineering department or workplace, are imbued with particular values and frames of meaning related to practice within those contexts. These contextually-situated values and shared meanings have implications for the types of activities that are recognized and valued within that context and have implications for how people see themselves and others in that space. Understanding participants' perceptions of the most valued or emphasized forms of engineering practice in a given context, and how it relates to their own thinking about and practice of engineering, provides insight into the forms of engineering work reinforced in local contexts and the culturally recognizable and valued ways of being an engineer. Holland and Lave (2009)'s notion of local (contentious) practice similarly describes the ways local contexts serve as sites where cultural meanings are negotiated, focusing on the inherent differences in power and status that, in part, stem from how closely one's own practice aligns with dominant values related to practice in that context. Jointly, these frameworks point to the potential implications of the forms of engineering practice emphasized in particular engineering contexts and how closely these align with participants' own priorities and values for how they are recognized and see themselves within the context(s) of engineering.

As described in depth in Chapter 3, data described in this chapter came from a card sort interview in which participants were asked to select approximately five practices from a deck of 26 that they perceive to be "most highly valued or emphasized" in particular educational, co-curricular, and/or professional engineering contexts in which they engage, followed by those they perceived to be "least valued or emphasized" and their feelings about the level of emphasis placed on these practices. In addition, participants were asked about those practices they personally considered to be most important in solving a complex problem in their field. These interviews were intended to promote participants' reflection on the values related to engineering practice dominant in their engineering training and work and how it relates to their own practice-related values. I begin by summarizing trends in the engineering practices across participants that they personally identified as most important in their field as well as those practices they perceived to be most and least emphasized in their educational and professional contexts. Next, I describe patterns related to participants' personal emphases on social and contextual factors in their engineering work and the extent to which they described alignment or dissonance between their own priorities and values and the emphases of the educational and professional engineering contexts in which they have engaged. The extent to which individuals' personal emphases align with the (often technical) dominant cultural values in the engineering settings they participate in may have implications for their perceptions of feeling valued and recognized in engineering.

**Overall Patterns of Emphasized Engineering Practices**

In this section, I provide an overview of the practices participants perceived to be most and least valued or emphasized in their educational and professional contexts, in response to

RQ1. The practices included in the card sort interview from which these data are drawn were developed based on literature related to engineering best practices (Passow & Passow, 2017), data from the first interview about participants' experiences solving complex problems, and feedback from undergraduate and graduate students. I organize this section into three main parts: the practices perceived to be most and least emphasized in undergraduate and graduate education contexts (both formal coursework and co-curriculars), the practices most and least emphasized in professional engineering contexts, and how these emphases in different engineering contexts align with the practices the 18 participants in this study phase personally identified as most important in solving a complex problem in their field. Sixteen participants described experiences in undergraduate settings, 10 in graduate education contexts, and nine respondents described experiences in varied professional engineering settings. Percentages of respondents reported below reflect the percent of respondents describing their experiences within each particular context (e.g., the percent of respondents who provided responses about a workplace context).

*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*. Thirty percent 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 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 respondents. Table 4 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 4: 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 | 0.00 | 0.00 |
| Interpret data, such as results from modeling, validation, and other data processing | 0.38 | 0.60 | 0.06 | 0.00 |

| | | | | |
|---|---|---|---|---|
| Collaborate with others by sharing expertise, ideas, resources etc. to achieve a common goal | 0.38 | 0.30 | 0.06 | 0.00 |
| Test and evaluate potential solutions | 0.44 | 0.20 | 0.00 | 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 | 0.00 |
| 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 | 0.00 |
| Develop details or schematics of potential solutions | 0.25 | 0.20 | 0.06 | 0.00 |
| 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 | 0.00 |
| 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 | 0.00 |
| 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 | 0.00 | 0.20 | 0.19 | 0.10 |
| Account for potential future impacts in developing a solution | 0.00 | 0.10 | 0.25 | 0.40 |
| Account for relationships between multiple elements or components of a project | 0.00 | 0.10 | 0.19 | 0.10 |
| Account for ways natural environment may affect or be affected by one's work | 0.00 | 0.10 | 0.25 | 0.30 |
| Account for the immediate problem context as it relates to one's work | 0.00 | 0.10 | 0.00 | 0.00 |
| Demonstrate social awareness, empathy, and self-awareness in interactions with others | 0.00 | 0.00 | 0.38 | 0.60 |
| Demonstrate leadership to ensure teams work effectively toward common goal | 0.00 | 0.00 | 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 capture 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 experience. Given this, 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 include those that focused on various aspects of medicine, military, engineering education, tooling, and automotive manufacturing. Across these various workplaces, a third 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 5 displays full workplace results.

**Table 5: 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 | 0.00 |
| Build tangible artifacts as models, prototypes, or working products | 0.33 | 0.00 |
| 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 | 0.00 |
| Analyze a problem and define the constraints | 0.22 | 0.11 |
| Account for relationships between multiple elements or components of a project | 0.22 | 0.00 |

| | | |
|---|---|---|
| Iterate on and improve on ideas or designs | 0.22 | 0.22 |
| Develop plans and procedures for experiments | 0.22 | 0.00 |
| 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 | 0.00 |
| Account for potential future impacts in developing a solution | 0.11 | 0.00 |
| Consider ethical responsibility | 0.11 | 0.00 |
| Interpret data, such as results from modeling, validation, and other data processing | 0.11 | 0.33 |
| Test and evaluate potential solutions | 0.11 | 0.00 |
| 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 | 0.00 | 0.11 |
| Account for ways natural environment may affect or be affected by one's work | 0.00 | 0.56 |
| Pitch your ideas and make a case for their value | 0.00 | 0.22 |
| Draw on science and engineering principles to predict outcomes | 0.00 | 0.11 |
| Follow proper data collection procedures | 0.00 | 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 of respondents (n=18) 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 several 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 6 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 6: 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 | 0.00 | 0.11 |
| Analyze a problem and define the constraints | 0.44 | 0.56 | 0.40 | 0.22 | 0.00 | 0.00 | 0.11 |
| Account for potential future impacts in developing a solution | 0.44 | 0.00 | 0.10 | 0.11 | 0.25 | 0.40 | 0.00 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Consider ethical responsibility | 0.44 | 0.06 | 0.10 | 0.11 | 0.19 | 0.10 | 0.00 |
| 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 | 0.00 | 0.33 |
| Account for relationships between multiple elements or components of a project | 0.33 | 0.00 | 0.10 | 0.22 | 0.19 | 0.10 | 0.00 |
| Come up with innovative ideas and approaches for addressing a problem | 0.28 | 0.06 | 0.30 | 0.44 | 0.19 | 0.00 | 0.22 |
| Test and evaluate potential solutions | 0.28 | 0.44 | 0.20 | 0.11 | 0.00 | 0.10 | 0.00 |
| 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 | 0.00 | 0.00 | 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 | 0.00 | 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 | 0.00 |
| Account for ways natural environment may affect or be affected by one's work | 0.17 | 0.00 | 0.10 | 0.00 | 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 | 0.00 | 0.20 | 0.33 | 0.19 | 0.10 | 0.00 |
| Develop plans and procedures for experiments | 0.17 | 0.25 | 0.30 | 0.22 | 0.19 | 0.00 | 0.00 |
| Pitch your ideas and make a case for their value | 0.11 | 0.06 | 0.20 | 0.00 | 0.13 | 0.10 | 0.22 |
| Demonstrate leadership to ensure teams work effectively toward common goal | 0.11 | 0.00 | 0.00 | 0.44 | 0.19 | 0.40 | 0.00 |
| 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 | 0.00 | 0.11 |
| Draw on science and engineering principles to predict outcomes | 0.06 | 0.31 | 0.20 | 0.00 | 0.13 | 0.00 | 0.11 |
| Follow proper data collection procedures | 0.00 | 0.19 | 0.10 | 0.00 | 0.25 | 0.00 | 0.11 |
| Account for the immediate problem context as it relates to one's work | 0.00 | 0.00 | 0.10 | 0.22 | 0.00 | 0.00 | 0.00 |

*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*

### Alignment Between Engineers' Values and Educational and Professional Emphases

Participants' accounts of the practices they personally named to be most important and those they perceived to be emphasized in their educational and professional experiences showed potential areas of dissonance, particularly related to respondents' perceptions of social and contextual aspects of engineering work. While the summaries reported in the prior sections show broad trends in the aspects of engineering perceived to be most and least valued in a variety of contexts, it is also important to understand the experiences of individual engineers and how contextual influences, and their own priorities, shape their experiences. In this section, I explore these experiences further, grouping respondents based on how strongly they personally prioritized social and contextual aspects of engineering work and the degree of perceived dissonance between their personal priorities and the predominant values and emphases of the engineering contexts in which they participated. I determined the extent to which participants prioritized social and contextual aspects of engineering work based on an analysis of all statements participants made about the aspects of engineering work they personally valued or prioritized, including, but not exclusive to, those practices participants identified as personally important in the card sort task. Similarly, the degree of dissonance experienced was based on an analysis of all statements participants made reflecting on their feelings of (dis)agreement or (mis)alignment with the emphases of the specific engineering contexts in which they have participated or the field of engineering more broadly. In this section, I use these two dimensions to group participants into nine possible groups with low, moderate, and high prioritization of social/cultural aspects and low, moderate, and high degrees of perceived dissonance between aspects of engineering work emphasized in various professional and educational contexts and participants' personal values related to engineering work (see Figure 3). I also describe participants' reflections on how this alignment relates to their feeling valued and recognized as engineers in their educational and professional contexts.

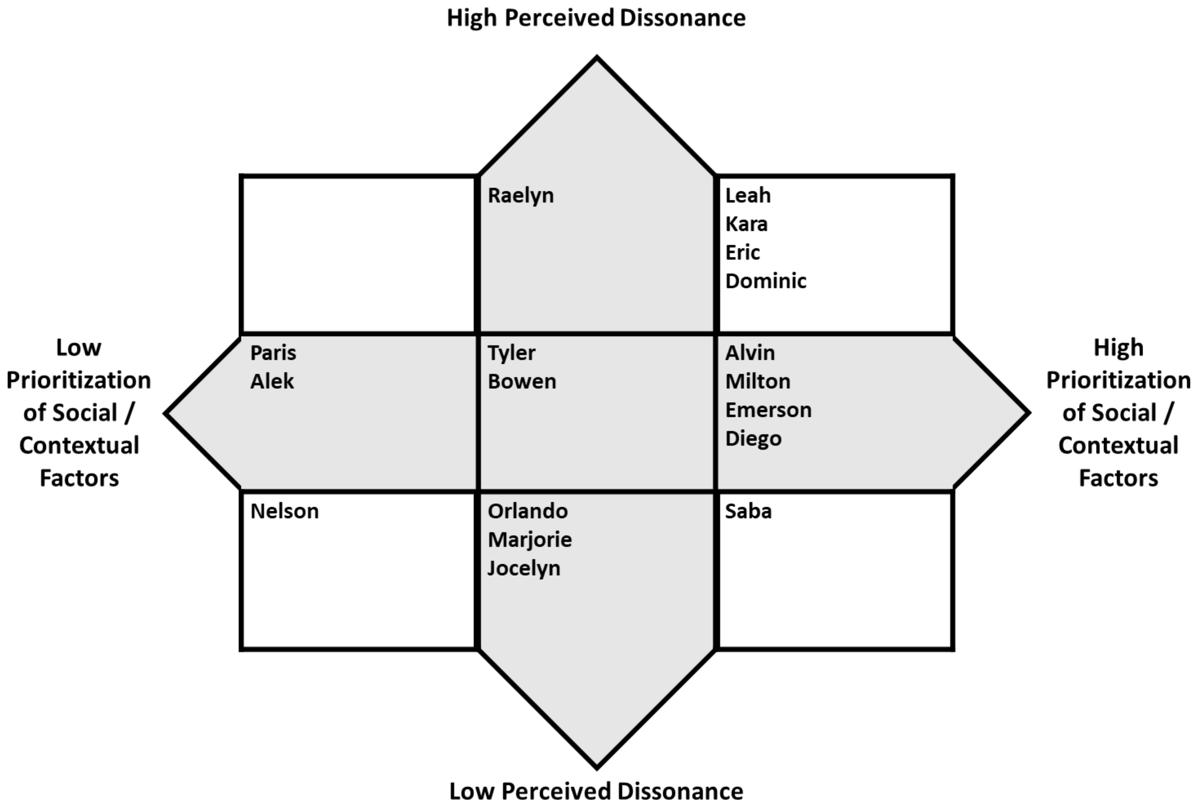


Figure 3: Categories of participants, by prioritization of social/contextual aspects of engineering and expressed level of dissonance between personal values and emphases of engineering contexts in which they engage

*Low Prioritization / Low Dissonance*

Based on his responses, I categorized Nelson this first category. He gave relatively low priority to social/contextual aspects of engineering work and experienced little dissonance between his personal priorities and the emphases of the engineering contexts in which he engaged.  At the time of the study, Nelson was an upper-level undergraduate student active in an aerospace-related student design team. His engagement in this design team was a primary focus of his undergraduate experience, and he held a high-level leadership role in the team, giving him substantial input into its activities. He described his personal priorities related to building tangible artifacts, iterating on potential solutions, collaborating with teammates toward a common goal, and accounting for how different components of a project are related. These foci were generally aligned with his work on his project team and, while he felt building tangible artifacts was among the least emphasized in his coursework, he identified it as among the most highly emphasized practices for his team in our card sort interview. Aside from desiring more emphasis on how to negotiate tradeoffs between different project components or requirements in his coursework, Nelson generally agreed with the emphases of his coursework and project team. When discussing the aspects of engineering work most valued on his project team, he explained “I think things that aren't really emphasized that all are, a lot of like the social, like ethical responsibility, social awareness, future impacts. Like they're not emphasized, but I don't think a project team is really the place to emphasize them.” He elaborated that a more appropriate place to emphasize these social or contextual aspects of engineering work was at the college level, explaining it often comes from “top down communication, like from the dean or something.” Similarly, he felt that ethical considerations were generally far removed from the work of a student project team and explained, “the only ethical thing related to rockets is missiles, and what we're doing certainly isn't even remotely close to a missile.” He acknowledged that while students’ training on the team could be applied in such a capacity, and that many students did apply their training in defense careers later on, the prospect of some later applying their rocketry knowledge to missile development did not shape team interactions. Generally, Nelson reported feeling valued and respected in the engineering contexts in which he engaged. However, he did note that he wished younger members of his project team were more receptive to his advice as an experienced member.

*Low Prioritization / Moderate Dissonance*

Two participants were grouped into this category and, while the two similarly gave low priority to social/contextual aspects of engineering work, the root of the dissonance between their personal priorities and focus of their engineering context differed substantially. Paris was a first-year engineering student who had only taken several engineering courses at that point in her education while Alek was a professional engineer with 18 years of experience and a co-owner of a medical device development consulting company.

At an early stage in her engineering journey, Paris' assessment of the emphases of her undergraduate education were primarily driven by her experiences in a project-based first year engineering course. She described personally prioritizing a range of aspects of engineering work, related to innovation, accounting for relationships between different components of a problem, interpreting data, collaborating with teammates toward a common goal, and considering the future impacts in coming up with engineering solutions. Despite her stated prioritization of considering future impacts, her responses fell into low-prioritization of social/contextual aspects of engineering category because the bulk of her responses related to her consistent interest in opportunities to develop her technical engineering skills. Her desire for greater technical skill development was also the source of moderate dissonance between her personal emphases and those of her undergraduate courses. She expressed frustration about the focus on accounting for the social/cultural context in engineering solutions in her introduction to engineering course. Reflecting on coursework emphases, she explained:

> I do feel like some things have been overemphasized. For example, I understand the social and cultural context. But I feel like it was emphasized too much as it made us feel more constrained into a specific thought because we had to consider everyone's wellbeing.

The course spent one full class session discussing these issues. Similarly, she felt the course emphasis on communication, while important, should be prioritized after technical mastery, explaining, “I wish we understood the facts first before we communicated.” Despite these tensions, when asked to reflect on the extent to which she felt her perspectives and work was valued, she described feeling recognized by her peers and instructors, stating, “All my instructors have been extremely nice and really open to ideas, even if they may disagree.”

As an experienced engineer and a co-founder of his company, Alek described a high level of alignment between the aspects of engineering work he personally valued and those emphasized in his professional experience – over which he had a great deal of control. He described a personal prioritization of innovation, building tangible artifacts, communicating effectively across professional backgrounds, and collaborating with others to achieve a common goal. Alek explained his personal focus and professional focus “tend to overlap.” He described accounting for social and cultural aspects of engineering to be among the least emphasized and least relevant practices in his professional work, elaborating:

> We're pretty focused on the medical devices and the ... There isn't a lot of sort of social aspect or cultural aspects beyond once you get to the potential clinical trial stuff or patient population stuff, but that tends to fall outside of what we would do on a project.

Similarly, while he acknowledged there is a lot of waste with single-use medical devices, accounting for environmental considerations was not a priority in his industry. Despite high levels of alignment between his personal and professional priorities, he expressed substantial concern about the emphases of his undergraduate engineering training, particularly related to educational emphases on engineering theory and abstract ideas with very little emphasis on practical skills and developing tangible engineering solutions. Alek explained that the lack of emphasis on applied and tangible problem-solving in his education served as motivation for founding a company that emphasizes these aspects of engineering work, stating "it goes back to kind of why we founded [company]. It's like we recognized there isn't that skillset available for especially a lot of startups." He expressed a desire to see these practical and technical skills more emphasized in the core engineering curriculum, and not just student project teams. Overall, Alek described feeling his skills and expertise had been highly valued in his engineering experiences, explaining the degree of alignment between his personal and company values, that others at his organization looked to him for his expertise, and the fact that he had always readily found employment.

*Low Prioritization / High Dissonance*

No participants who expressed a low prioritization of the social and contextual aspects of engineering work also expressed a high degree of dissonance between their personal priorities and those of the engineering contexts in which they have engaged.

*Moderate Prioritization/Low Dissonance*

The three participants whose responses indicated a moderate degree of personal emphasis on cultural/social aspects of engineering work and low overall dissonance were all doctoral students with generally positive relationships with their PhD supervisors. The first of these participants, Orlando, conducted space-related research in an interdisciplinary engineering lab. While the aspects of engineering work that he explicitly named as important in addressing a problem in the field were primarily technical, aside from ethical considerations related to the importance of accurate data collection, his responses highlighted a degree of recognition and valuing of social/contextual aspects of engineering work. For example, Orlando described his experiences designing an experimental course as an undergraduate, focused on cross-disciplinary problem solving that foregrounded cultural and contextual considerations. While these broader aspects of engineering work were of some importance to him, he explained that his PhD work did not emphasize these areas and did not indicate concern related to the emphasis of his program. For example, discussing social/cultural awareness, he explained “I never have to worry about how my experiment affects—the scientific community, sure—but not society […] none of that ever even approaches what we’re doing.” In general, he described a high degree of alignment between his personal priorities and his PhD work, explaining his advisor valued many of the same aspects of engineering. He described feeling well-recognized and valued in both his undergraduate and graduate experiences, citing awards, praise for his work, and his supervisors’ confidence in his abilities.

The other two participants whose responses were placed into this category, Marjorie and Jocelyn, worked in highly interdisciplinary and human-centered labs and areas of study, though their academic/professional trajectories varied substantially. Neither participant explicitly expressed a strong prioritization of social/contextual aspects of engineering work, but their discussion of their educational and professional experiences and the nature of work they engaged in in their doctoral programs suggested a moderate personal emphasis on social/contextual factors. Both Marjorie and Jocelyn described highly prioritizing research-related aspects of engineering work. Marjorie also stressed ethics and incorporating ideas from other fields, given the human-centered and interdisciplinary nature of her research. Overall, she described the aspects of engineering emphasized in her academic experiences to largely overlap with her personal priorities, though she expressed a desire for less emphasis on technical communication, particularly around conference submissions. In contrast, Jocelyn personally emphasized that technical and non-technical communication were important to her, explaining she often needed to coordinate with others outside of her field for her work related to a human-welfare and law enforcement area of study. Jocelyn explained that in her PhD she "happened to be in a research group that's very socially aware" and that strongly stressed ethical considerations, though she perceived her lab to be an exception relative to other engineering labs. Both Marjorie and Jocelyn described their engineering departments as largely absent of individuals who emphasized social awareness in their interactions with others. Marjorie referred to her department as "a very antisocial kind of environment" and Jocelyn suggested "the people that want to be an engineer are sometimes wanting be there because you don't have to be around a lot of people […] there's definitely no emphasis put on social awareness or empathy at all." While both women discussed social awareness as among the least emphasized aspects of engineering, neither described the emphases of their educational or professional environments as a significant source of conflict for them personally. Both Marjorie and Jocelyn described feeling valued and recognized in their respective environments. Marjorie explained her strengths were mostly well-aligned with her advisor's priorities. Jocelyn described being recognized for different strengths in her prior military service, explaining she stood out because of her analytical skills and teaching ability, contrasting this with her experiences in academia, where she felt she her leadership and social skills she honed through her military experience were more valued.

*Moderate Prioritization, Moderate Dissonance*

Two participants' responses indicated a moderate degree of prioritization of social and contextual aspects of engineering work and a moderate degree of dissonance between their personal priorities and those of their engineering environments. Tyler was an undergraduate robotics engineering student heavily involved in an automotive student project team. Bowen was a recent PhD graduate in biomedical engineering who worked for an engineering startup. Though neither cited contextual aspects of engineering work as among their top priorities, both men described valuing social and contextual aspects of engineering work to an extent and expressed mixed feelings on the degree to which these aspects should be emphasized in their engineering educational and professional environments. For instance, Tyler expressed frustration with what he perceived to be an underemphasis on the future impacts of engineering solutions, explaining:

> For potential future impacts in developing a solution, also, something that I would have preferred a little bit more. I would have preferred if that had a little bit more influence in the classes because if potential future impacts were a little bit more emphasized, maybe you'd have more people taking global warming seriously, or the people who are actually designing the engineering problems would actually take future effects such as global warming, such as whatever into account

He described a similar lack of emphasis on interpersonal and contextual aspects of engineering, stating "All that social and cultural stuff is miles away." According to Tyler, the automotive project team in which he was heavily involved also did not emphasize these aspects of engineering, as he explained "Again, no – it was not even close to what we were thinking about." However, while he acknowledged he did not always agree with the engineering practices most emphasized, particularly within his courses, he did not necessarily perceive this to be a major problem, stating:

> In some cases, I would have preferred changing things in specific ways or emphasizing different cards, but a lot of times, especially looking back on it, I go, "Okay. Well, I can see why you did this this way," and it makes…it's not bad.

Generally, Tyler described feeling recognized and valued in his academic and project team contexts and that the aspects of engineering work emphasized aligned with his values.

Like Tyler, Bowen described an awareness of some social or contextual aspects of engineering work and expressed an interest in seeing these aspects emphasized more highly. He explained that he would like to see more emphasis on social and environmental issues in the engineering startup he worked for, but acknowledged that, as a small profit-driven enterprise, such emphases are not necessarily realistic, stating:

> But because you're in a business, these things are often secondary considerations. I would love to be in a business where we're able to be 100% transparent with customers, where we're able to offer them something at cost, where we're able to give things to people that aren't able to afford them. And to do all this without impacting the environment. But that just isn't possible.

He described keeping the impacts of engineering work in his mind, given the importance justifying grant funding applications, but also for him personally in explaining his work to family members from a non-engineering background. About his educational experiences, he explained that while his university tried to “emphasize more of the social awareness and cultural context” these aspects were “not emphasized, but [the university community is] not antagonistic either.” He explained that he was well aware of ethical and interpersonal issues given his wife’s background as a social worker, but that such things were “just kind of there in the background” in his own educational experiences. When asked about the extent to which he felt recognized and valued by those in his engineering environments he answered that this recognition is dependent on the extent to which his personal skills align with the priorities of a given organization. For example, he described himself as good at communication and leadership but that, because these are not always as emphasized in engineering, they “can get kind of lost” in terms of recognition.

*Moderate Prioritization / High Dissonance*

Raelyn was the one participant who placed a moderate emphasis on social and contextual aspects of engineering work and described a high degree of dissonance between her personal priorities and those of her department. Raelyn was a master’s degree student in materials engineering with over a year of industry co-op experience. She described personally prioritizing engineering skills related to testing solutions, iteration, pitching her ideas, technical communication, and accounting for future impacts in her work. She described her academic training similarly emphasizing testing solutions and technical communication, but felt her other priorities were under emphasized. She also raised concerns that her department placed little emphasis on the cultural context in which a problem is embedded, on accounting for the natural environment, and, most troubling to her, on social awareness in interactions with others. She cited the lack of diversity in engineering as a potential contributor to this issue, explaining:

> So, I think social awareness is a big one. I think I kind of mentioned that. Like people say things that are kind of offensive to groups of people, I think, all the time just because we go to like, at least engineering and machines are very like homogenous in terms of who is there.

While an underemphasis on social and contextual aspects of engineering in her studies (which she contrasted to her workplace experiences) was a source of some dissonance, Raelyn described the most frustration was related to her department's lack of emphasis on building and facilitating "hard skills, and just like maybe basic circuit design" relevant in engineering industry. She also described a disconnect between the institution's stated priorities related to preparing students for engineering industry and university policies that made it difficult for her to pursue relevant experience, explaining:

> I think it's so ridiculous that they make such a big deal about hands-on experience – like, we want you to go out into the workforce, internships and such, but at least in the master's programs they make it very difficult to do so and like – we're not going to give you time off. […] They said one thing and did another.

Ultimately, Raelyn had to leave the university for a term in order to pursue an internship, which caused her issues related to the deferral of her student loans. Raelyn explained that, while she generally felt appreciated and recognized for her engineering abilities in her work contexts, she felt less recognized in her educational experiences because of the disconnect between the areas and future careers stressed by her department and her own area of work and expertise, stating "everyone was kind of like, 'that's not really relevant,' even though I thought it was."

*High Prioritization / Low Dissonance*

The one participant whose responses fell in this category was Saba, a first-year undergraduate student who had not year declared a specific engineering major. She described a strong personal emphasis on many of the social/contextual aspects of engineering including engineering ethics, accounting for future and human impacts in engineering solutions, and collaboration, in addition to skills related to iterating and evaluating engineering solutions. She participated in a first year project-based introduction to engineering course that involved engagement with a stakeholder with a disability to design an adaptive game. In that course, she described that innovation, teamwork, and a consideration of the social context were highly emphasized. She also described ethics as being attended to in her introduction to engineering course but less so elsewhere. Saba contrasted the focus of the majority of her undergrad engineering courses from her introductory course, explaining "social things aren't exactly emphasized" in her coursework, and that much of it focuses on design processes and technical skills. However, while she expressed a hope that social/contextual aspects of engineering would be reintroduced in her more advanced courses, she did not necessarily perceive a problem with the narrower technical focus of much of her engineering coursework, explaining:

> And I've kind of realized that at this stage, they just want to build your skills because no one just knows how to code. It's not always intuitive and there are a lot of nuances in learning that. So, I think look in that phase of the program so there's not really time or it's not quite relevant to tie it in to other things as of yet.

When asked about how she perceived her individual values and skills are valued or not in her engineering contexts, she said she felt more valued in her introductory class because the focus was more closely applied to engineering applications and the human impact. She explained "what we were taught in [introduction to engineering course] was a bit more realistic and that's to like what I think is important because it was more like real life." She also described feeling more that her individual perspectives were more valued in her humanities courses, which integrated broad-ranging discussion.

*High Prioritization, Moderate Dissonance*

Four participants placed a high degree of personal emphasis on the social/cultural aspects of engineering work and described moderate levels of dissonance between their personal priorities and those of the engineering contexts in which they engaged. One participant, Emerson, was a lower-level undergraduate student, while the other three were doctoral students (Alvin, Diego, and Milton). All participants in this category described studying and participating in relatively interdisciplinary and human-centered engineering areas. These participants often contrasted the more human-centered contexts in which they sought to engage with what they perceived to be predominant values of engineering overall, which was generally the source of perceived dissonance identified by these participants.

Emerson, an undergraduate student in biomedical engineering, described a high degree of personal emphasis on social/contextual aspects of engineering work such as ethics and accounting for the social and cultural context in which a problem is embedded. He expressed a desire for greater emphasis on social awareness in his courses that includes specific strategies for implementing this in engineering contexts. He explained that he got some of this emphasis through his introductory engineering course (which was more socially-oriented than some others), and through extracurricular experiences that he had to seek out:

> I would like to see a little more, considering this is the social or cultural context in which a project is embedded. I think I've sought out projects where that is really integral to the project or integral to the class or group, whatever. I don't think that's as widespread as I would like it to be. I think that's really important. I would like to see that earlier on. My particular [introduction to engineering] class was really good about that, but I talked to a lot of my peers and theirs were not. They were building a blimp, and that was it.

He explained that, in his biomedical engineering courses there was some consideration of human-related and ethical considerations, but perceived for other engineering majors “that’s not on their radar at all.” Emerson explained that he generally felt quite respected and valued on campus, but that instructors and peers in his engineering courses made more stereotypical assumptions about his and other engineers' (narrow) academic interests.

Diego and Alvin were both Industrial Engineering PhD students who worked in less traditionally technical engineering roles prior to going back for their PhDs. Diego worked in engineering education and Alvin worked in a health system and had a background in Public Health in addition to his engineering training. Both men described valuing a range of technical and social/contextual aspects of engineering work. Alvin placed a particularly high emphasis on accounting for social context and future impacts in his own work, which he felt were closely related, stating the following when asked about the aspects of engineering he felt were most important:

> So ... thinking about the impacts, especially impacts within the social and cultural context for the problem itself, of like, "what is this going to do both immediately and in the future?" for whatever the larger problem we're trying to solve.

Diego placed particularly high personal emphasis on ethical responsibility describing it as "the best one of all," among the aspects of engineering work discussed in our conversation. Both Alvin and Diego described the social/contextual aspects of engineering work they personally prioritized most highly as key aspects of their work prior to their PhD programs. For Alvin, his previous work as an engineer in a healthcare setting aligned well with his personal prioritization of human and contextual aspects of engineering. He explained, "I loved the fact that all of the work we did was always brought back to the patient level. And so I think [the emphases of my past workplace] really well-aligned with my own personal interests." In Diego's prior work developing new engineering curriculum for undergraduate students, he described ethical considerations as a key priority, explaining it factored into course decisions from homework amounts to course structure, particularly related to how to disincentivize student cheating. He also described the influence of ethics in his work developing example problems for courses, explaining “we have to do examples that are ethical and responsible. When we are more dealing with real examples, from the real, industry examples or whatever, those should be an ethical examples.”

While both Alvin and Diego had prior professional experiences that emphasized human-oriented aspects of engineering work, they perceived these aspects to be undervalued in engineering education more broadly. Both Alvin and Diego conducted PhD research that related to human and contextual aspects of engineering work. However, neither man felt that this emphasis was representative of engineering as a whole. Alvin explained that, while he prioritized social and contextual aspects of engineering in his own PhD research and had an advisor who allowed him to do so, he felt that these aspects were not particularly valued in his larger undergraduate or graduate engineering experiences, stating:

> I do think that starting to get more of [...] the collaboration and the social and cultural context, into an undergraduate setting; the more that we could do that would be great. I think within my PhD that these are there but it's largely, like, I want them to be there so I am bringing them and I am driving them. It's not necessarily... I think that someone could easily get through an IOE PhD without thinking about the social or cultural context of the work they're doing.

Similarly, he perceived conversations around social awareness and empathy in interpersonal relationships to be generally lacking, explaining, “Those words, I don't think I've ever heard discussed in an IOE setting.” Likewise, he described ethical responsibility as “something that is inherently expected but is certainly not explicitly mentioned.” Diego also described an underemphasis in his educational experiences related to important social and contextual aspects of engineering work, particularly how such principles may actually be applied. He expressed a desire for greater emphasis on the future impacts of engineering solutions and drawing on ideas or knowledge from other (more human-centered) fields of study in his PhD program. He felt this underemphasis was consistent across his educational experiences, stating “I think it's the same think, undergrad, and then masters. And that's a big problem." He cited his desire to see a greater emphasis on contextual considerations as a key goal and motivator in his engineering education work, describing the difficulty of teaching students how to put such values into practice, explaining:

> Sure, you can create a really good model. You can design a really good model. You can understand this, all the technical perspectives, and the engineering perspectives, background, whatever, and you can also learn about the ethical responsibility and this stuff, but from they're jumping to how you are going to apply all this to a real life scenario, it's quite difficult. And I guess that always happens. Again, and on my undergrad, and on my masters, the place that I work with, that happened a lot. And it's quite difficult to adjust to curriculum in general.

Diego described the consequences of the challenge of integrating these non-technical aspects of engineering work into the curriculum, explaining many engineering graduates "don't have knowledge of different aspects that affect the problem." Interestingly, he described these consequences as "not engineering aspects, but other fields' aspects – social aspects, background aspects…" Overall, Diego described feeling recognized and valued for his research and teaching skills in both his academic and professional experiences.

Milton, an engineer in an interdisciplinary design doctoral program, primarily discussed his personal values relative to those he perceives in the field of engineering broadly. He placed a high degree of personal emphasis on innovation and entrepreneurship, as well as social/contextual aspects of engineering including fostering social ties, having good interpersonal skills, ethics, and accounting for the social and cultural context in which engineering problems are embedded. Though he acknowledged that many of these things were highly emphasized in his interdisciplinary program, he described these aspects of engineering work as largely underemphasized in the field of engineering overall. Regarding ethics, he explained:

> Ethics is under-emphasized across engineering, period. It's not built in to the curriculum. Only ethics class, well, the only class that talks about ethics in a

> major way I know of is in IOE. I think the academic structure attempts, but is not very good at looking at, ethical behavior. It's more of a legal risk perspective.

He also spoke about an underemphasis in engineering about the importance of networking and understanding how to develop and maintain positive relationships with others. However, he explained that, in business, short of sacrificing his morals, he felt that the appropriate emphasis in a given project should be client driven. He argued:

> I'm a very numbers-driven person and one of the things I understand is that you make a lot of concessions when you own your own business. And it really is about delivering what the customer wants. It doesn't mean that you sacrifice your morals, but as long as you have no moral conflicts, you don't have any sacred cows. You decide this is what matters, and it depends on what the client is looking for at that point.

When asked about the extent to which he felt valued in his engineering contexts, he felt that he did not know or appreciate his own skills early in his undergraduate career and, upon coming back to school as an adult, he generally felt respected but acknowledged that his cumulated experience and the credibility he enjoyed in his previous roles did not necessarily transfer into the academic context.

*High Prioritization, High Dissonance*

Four participants described the highest degrees of prioritization of social and contextual aspects of engineering work and the highest degrees of perceived dissonance between their personal priorities and those of their academic and professional environments. For these four participants, the perceived lack of emphasis on social and contextual aspects of engineering work was at the core of their experiences of dissonance across a range of engineering environments, which also had implications for these participants' experiences of feeling valued or recognized within engineering. Dominic, who was a PhD student in biomedical engineering, described a high degree of personal emphasis on social, ethical, environmental, and future impact-related aspects of engineering work. In his own work, he discussed selecting projects based on the number of people who might benefit from his work and the degree of this benefit. He described engineering education as lacking in “the people skills part” of engineering and expressed frustration with the academic culture and often solitary nature of academic engineering. He described academic engineering as “miserable” and expressed a desire to work outside of academia upon completing his degree. He felt that people skills were largely lacking among academics in engineering and, that while his advisor highly valued these skills and recruited students with high degrees of social awareness, few students in his lab wanted to go into academia despite his advisors’ encouragement. He acknowledged that his university was making some efforts to emphasize social aspects of engineering work but explained he “never had a course that taught that” and that conversations around these aspects were only likely to occur in the event of a problem. He explained that, while he generally felt recognized and respected for his skills and perspectives, he felt his personal emphasis on ethics and the impacts of his work were underappreciated, explaining “I think a lot of people might basically roll their eyes at that kind of stuff. I think it’s really important.”

Eric was a PhD student in environmental engineering who similarly placed a high personal emphasis on ethics and understanding how engineering solutions related to the larger social context and natural environment, in addition to research and technical communication skills. He expressed substantial frustration that many of the human and societal aspects of engineering that he valued highly, with the exception of a consideration of the natural environment within his environmental engineering program, were among the least emphasized in his engineering education experiences. He explained that an emphasis on the strictly technical aspects of engineering “gives this impression that you as an engineer, all you need to care about is making sure that your design works. But it does not matter what the impact of that design is.”

He acknowledged that integrating social and contextual aspects of engineering in technical engineering and science courses might be challenging, but still felt more should be done to address these issues. He explained that, even in courses such as wastewater treatment, “never did we talk about […] what kind of social or cultural impact our designs would have” and cited a number of community impacts relevant to the design of wastewater treatment plants. He described slow growing awareness among engineers about the importance of thinking about societal impacts of their work, and expressed a desire for more engagement around these issues, particularly with an eye toward recruiting more women and racial and ethnic minorities into the field. Given the lack of emphasis of social and contextual aspects of engineering in his graduate and undergraduate training, Eric sought other opportunities to engage with these issues and develop his skills. He started an environmental justice blog to consider the human impacts of environmental engineering solutions, such as gentrification and displacement of current residents stemming from implementation of green architecture in cities such as Detroit. Despite the degree of tension Eric described between his personal values and those of the field, he described generally feeling recognized and valued, citing a positive relationship with his advisor.

Kara completed her bachelors and master’s degrees mechanical engineering and design science, respectively, and had worked in the auto industry for several years. She expressed an extremely high personal emphasis on social and contextual aspects of engineering work, including social awareness, accounting for social, environmental, and future impacts, and engineering work. She described these aspects of engineering as inextricable from other aspects of engineering design, explaining, “From engineering to social to environmental, there are multiple relationships between all of them. It can be a brain explosion, but they’re all connected and they’re all important.” She described a tension between these values and the emphasis of the bulk of her engineering experiences. At the time of our interview, she had recently started working in a division within her company that she described as “very culturally progressive” and “human-centered,” which she contrasted with her experiences in the auto industry more broadly. She expressed frustration about a narrow technical focus in her experiences in engineering education and described seeking out extracurricular opportunities to engage with social aspects of engineering work, explaining, “It’s important to think about some of these social aspects that are neglected from what you see in your standard required engineering course.” Kara explained that while she felt valued in her current professional role that aligns well with her perspectives and skills, she did not feel recognized or valued for these skills in her formal educational experiences. She explained that she made a conscious decision to focus a disproportionate amount of her time and energy on her extracurricular activities, citing this choice as key to her current success, stating “Having those different perspectives and being exposed to those different perspectives actually got me to where I am now, which I feel is very rewarding just to be in the work that I'm doing now.” However, she elaborated, “I wouldn't have gotten there had I focused specifically on all of the things that I think the engineering curriculum really values.”

Like others in this category, Leah placed a strong personal emphasis on accounting for the social context in her engineering work, as well as interpersonal and social awareness and described substantial dissonance between these and aspects of engineering work emphasized in her educational and professional experiences. Leah earned a bachelor’s degree in mechanical engineering and then pursued a job in a manufacturing company. At the time of our interview, Leah had recently quit her engineering job and was in the process of transitioning into a PhD program in design. She cited tensions around her former employers’ values and culture as key reasons in her decision to leave the job and pursue another area of study. In her former workplace, she described a disproportionate emphasis on fundamental engineering work, which she felt was irrelevant to the demands of the job. Leah expressed great frustration with her company's lack of emphasis on the social context, describing it as "actively ignored" and explaining "they believed their user to be basically themselves." She also described a culture that did not value collaboration, though this was something she was able to increasingly advocate for in her time there. She expressed a similar frustration with the emphasis of her undergraduate coursework, particularly a lack of consideration about the impacts of engineering solutions, explaining:

> There's no future for any solutions because it all ends at the end of the course. So there's really no evaluation of what it could mean going forward. That's not ever incorporated into engineering, my experience with that. […] At most, there's like, think of how much you would sell this for?

Like Kara, Leah sought out extracurricular experiences that better connected with aspects of engineering work she valued highly, including personal multidisciplinary design work and participation in an organization that focused on social innovation and human and contextual aspects of problem solving. She explained that she spent much of her energy on these extracurriculars because they more closely aligned with her values. Leah explained that, in her workplace, her contributions were valued, but that she felt she could not bring her whole self into her work. She explained:

> I think one of the biggest reasons I left, I mean, I always say this is the biggest reason I left my job, but there's like 1,000 of them. But I think a big one is that I was not valued for what I was able to contribute. They valued what I contributed, but they were only seeing like 5% of me because they weren't allowing me to be everything that I could be. So sure they valued everything that I gave them, but they weren't allowing me the space to be all of it, to be even more than what they were even possibly seeing. I know I could have contributed a lot more if the... I know I do contribute a lot more. If the situation is slightly different.

**Summary of Findings**

In this chapter, I drew on interviews with participants about the engineering practices they perceived to be most and least valued or emphasized in the engineering contexts in which they engaged and the extent to which these aligned with their personal values. My findings provided both summary data of overall trends in aspects of engineering work emphasized as well as the experiences of participants classified into different groups based on the extent to which they personally valued social and contextual aspects of engineering work and the degree of dissonance they described between their personal values related to engineering work and what they perceive to be emphasized in engineering. Broadly, these findings align with previous literature that suggests social and contextual aspects of engineering work are generally under-emphasized. By looking more closely into my participants' experiences in their particular engineering programs and work settings, I was able to see how the emphasis on different aspects of engineering work varied across this range of settings and, importantly, the dissonance that resulted for engineers who identified disconnects between what they valued and what was emphasized in their engineering contexts.

In educational contexts, participants described technical communication, problem analysis and solution development, collaboration, and several research-related practices as among the most highly valued. 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.

Exploring patterns among individual participants' cases provided greater insight into the nature and extent of tension respondent's experienced related to the aspects of engineering work emphasized in their educational and professional contexts. While five of 18 participants expressed little to no dissonance related to the emphases of engineering contexts in which they engage, the majority of participants did express some areas where they disagreed with or experienced tension related to what was emphasized in their engineering education and/or work environments. Relatedly, a majority of participants described at least moderately valuing social or contextual aspects of engineering personally, regardless of if they experienced dissonance related to this emphasis. For a majority of participants who discussed any disagreement, frustration, or dissonance related to the emphasis of engineering, the source of that tension was related to a desire to see greater emphasis on interpersonal, social, and contextual aspects of engineering. In addition, several participants also expressed a desire for a greater emphasis on environmental impacts, engineering ethics, and interdisciplinarity. Participants who described the highest degrees of dissonance and/or who most highly prioritized social/contextual factors in their own work most commonly cited this lack of emphasis as the source of tension. However, several participants, including two with low personal prioritization of social/contextual aspects of engineering work, and one who placed a moderate degree of emphasis on these aspects, cited other sources of dissonance, including a desire for more hands on building and practical skill development. Figure 4 summarizes the sources of dissonance for participants, organized in the nine categories of social/cultural emphasis and expressed level of dissonance.

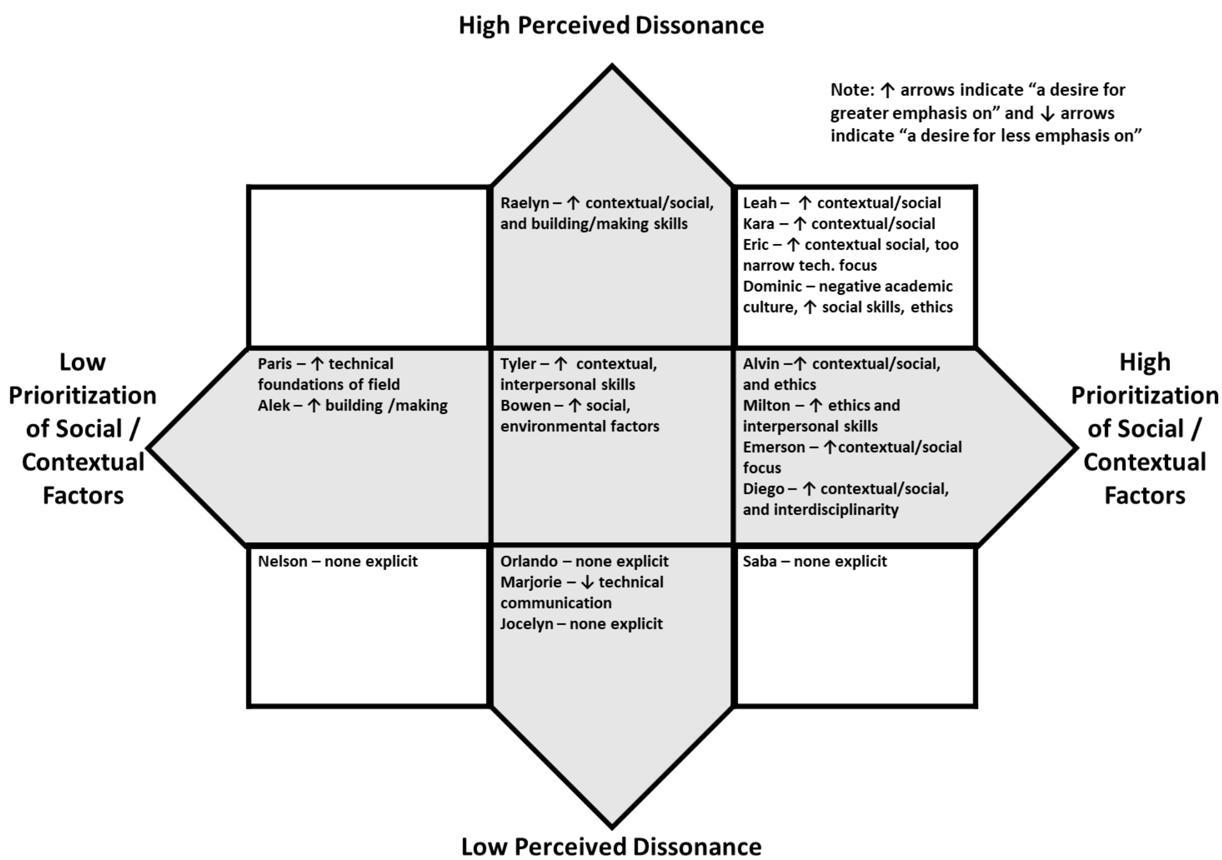


Figure 4: Categories of participants, by prioritization of social/contextual aspects of engineering and expressed level of dissonance, with source of dissonance between emphasis of engineering environments and personal values

## Key Insights

Beyond the broad trends described above, these findings yield several key insights on how engineering practice is perceived by different engineers. Some engineers fully accepted a lack of emphasis on contextual aspects of engineering in their academic or professional work. Several participants did not view social or contextual considerations as relevant to their coursework, work, or team experiences, and others explicitly described putting aside any such consideration of how their work might be applied. For example, Nelson acknowledged that a number of students on his rocketry team eventually applied their skills to develop missiles, but felt this application was too far removed from the day-to-day work of his team to influence team interactions or decision making. Paris, an early career undergraduate student who similarly placed a low degree of emphasis on social and contextual considerations, was frustrated that her "introduction to engineering" course devoted an entire class session such considerations; she argued  that students should first develop what she perceived to be core technical proficiencies. Her case highlights how, even in light of local efforts to emphasize contextual aspects of engineering work, widespread beliefs about the primacy of technical considerations can persist. Even some participants who described valuing contextual aspects of engineering work discussed such contextual considerations as peripheral to the core of their engineering work. For example, Orlando, who expressed emphasizing social and contextual considerations in a course he developed and taught in his undergraduate career, explained that in his current space-related research he "never [had] to worry" about how his work affects society. Although Diego placed a strong emphasis on social and contextual engineering skills in his prior professional work developing a new engineering curriculum, he referred to these competencies as "non-engineering aspects" of the work.

Not all participants personally regarded contextual aspects of engineering work to be unimportant or peripheral to their practice of engineering, despite their underemphasis in participants' engineering programs or work overall. In fact, insufficient emphasis on social or contextual engineering work was a source of at least moderate dissonance for a majority of respondents. The consequences of this dissonance had the strongest impact on participants who most strongly valued contextual aspects of engineering work and who perceived these to be largely missing in their engineering schooling or workplaces. These participants, including Dominic, Kara, and Leah, felt extreme dissonance and even a desire to avoid or minimize time spent engaging in settings where an underemphasis on contextual considerations was most apparent to them. Those participants who described a strong personal prioritization of contextual aspects of engineering but expressed less dissonance were generally very early in their engineering careers (e.g., Saba and Emerson) or currently pursuing graduate work in a lab that placed a higher emphasis on social or contextual engineering work (e.g., Alvin, Diego, and Milton). Notably, participants who characterized their current engineering environments as socially or contextually-oriented viewed these settings as exceptions to what they perceived to be typical of engineering work settings.

These findings suggest several ways that ideas of "typical" or "core" engineering work as primarily technical may be reproduced. The well-documented entrenched beliefs about engineering's predominantly or exclusively technical focus (e.g. Cech, 2013; Faulkner, 2007; Riley, 2008; Williams, 2002) can persist despite the work of individuals engineers whose own values and practice counter this emphasis, when the engineering settings in which they engage do not facilitate the consideration of social and contextual factors. Several participants described how contextual aspects important to them were cast as irrelevant or outside the scope of their work. For example, Leah explained that in her professional work experience social and contextual considerations were "actively ignored" by her supervisors while Bowen described how his company's small size and profit motive made a consideration of environmental or social concerns unrealistic, despite the fact that he personally cared about such factors. Even in engineering settings where some contextual aspects may be valued or emphasized more strongly, other social or contextual considerations may be neglected. For example, Eric's environmental engineering courses stressed emphasized environmental considerations but did not raise issues related to the human impact of such work, even of tangible artifacts such as a wastewater treatment plant.

Structural-level forces may also constrict what engineers learn. Raelyn recounted how college-wide policies prohibited her from pursuing an internship as a master's student without temporarily disenrolling from her degree program despite her program's espoused valuing of practical experience. In addition, the references to the social or contextual aspects of engineering work that students described came primarily from their introductory engineering courses or through college-wide email communication rather than from consistent and explicit attention in their coursework. Other students looked to extracurricular activities for contextually-oriented experiences, lacking exposure to such considerations in their engineering coursework. A consistent underemphasis on contextual aspects of engineering in core engineering courses points to one way the narrow technical focus of engineering may be reproduced; if instructors do not emphasize contextual factors in their teaching and do not ask students to develop the skills needed to account for these factors, it is unlikely that students will spontaneously account for them as professional engineers or come to understand them as core to engineering practice. Social practice theory holds that culturally held beliefs, such as those regarding what constitutes (engineering) practice, are reproduced by the day-to-day actions (or, in this case, inaction) of individuals. In this way, the neglect of contextual aspects in everyday engineering practice works to reinforce narrow images of what engineers do.

## Chapter 5: Factors Considered in Solving Complex Problems and Relevant Prior Experiences

Though there have been a number of high-level calls for increased attention to contextual aspects of engineering and advocacy for the education of socially engaged engineers (e.g., ABET, 2017; Amadei & Wallace, 2009; Lucena, Schneider, & Leydens, 2010; UNESCO, 2010), the change has been slow to come (Godfrey, 2014). Why, in light of such calls, does a predominant focus on technical aspects of engineering persist? Cech's (2014, 2014b) work, which showed that engineering students' declining public welfare beliefs were linked to their perceptions of the extent to which their programs emphasized ethical and social issues, suggests engineers' experiences within given engineering contexts may in fact perpetuate this narrow technical focus. However, more work is needed to understand specifically *how* this underemphasis on contextual aspects of engineering work may be reproduced in these settings.

Social practice theory argues that day-to-day practice both reflects and reifies shared values and shared meanings in a given context (Holland et al., 1998). In this chapter I examine how dominant engineering values were reflected in types of engineering activities that participants described as recognized and valued within their educational and work settings, and how engaging in forms of practice most closely aligned with those dominant values were most likely to lead to recognition by others as engineering. Consequently, engineers may be most likely to engage in engineering practices that most closely align with those they perceive to be most valued in their engineering work and educational settings. However, individuals also bring with them into these contexts prior experiences and personal values that may differ from these dominant values. Thus, what Holland and Lave refer to as “history in person” may also inform engineers’ work, potentially introducing variation into the day-to-day engineering practice that constitutes work in a given setting. The same mechanism through which narrow ideas of engineering work are reproduced in engineering contexts is thus also a route to change.

In this chapter, I focus on participants’ descriptions of their engineering practice by characterizing the types of factors they attended to in solving complex problems and the educational, professional, and/or life experiences shaped their attention to various factors. Specifically, I addressed the following questions:

> RQ3: What types of factors do engineers most commonly attend to in addressing complex engineering problems?
>
> RQ4: What educational, professional, and personal experiences do engineers cite as influential in their consideration of various factors when solving engineering problems?

I drew on interview data from 46 participants who described their experiences solving a particular complex engineering problem, as well as their experiences in engineering education and/or work settings. I organize these findings into six categories of factors related to these practices and experiences: 1) technical, 2) immediate conditions and constraints, 3) stakeholders, 4) internal coordination, 5) contextual, and 6) interrelationships between elements of a problem. In each sub-section, I describe the factors that comprise each category using illustrative examples and report the frequency of mentions in participants’ descriptions of their experiences solving a complex engineering problem. I highlight patterns in these reports, paying particular attention to those experiences that participants identified as influential in their consideration of social and contextual aspects of engineering work.

### Frequency of Factors Considered and Related Prior Experience

In the sections that follow, I describe each of the six broad categories of factors participants in my study considered in addressing a complex engineering problem and prior experiences they cited as influential in considering that type of factor in their engineering work. My analysis includes 14 types of factors, organized into six broad categories. The original factors were derived inductively, though also informed by the literature guiding the study (e.g., (Hayden, 2011; JHU, 2016; NAE, 2004; Rebovich, 2004). In each subsection, I describe the category and rationale for grouping the factors within it, define the individual factors and provide example excerpts from participant interviews for each. In addition, I provide a count of participants who described accounting for each factor in their experiences solving a complex engineering problem. While I report the counts of the total number of participants citing any prior experience shaping their attention to each factor, some participants described experiences across multiple contexts as contributing to their attention to particular factors. In addition, I describe the prior experiences study participants named as informing their consideration of each factor to provide some insight into the particular experiences that shaped participants' attention to different aspects of a complex engineering problem. While the categories, and the factors that comprise each, are discussed individually, in many cases participants' consideration of various factors were intertwined with one another, as one might expect when addressing complex problems. Table 7 provides an overview of the six categories of factors, with definitions and counts of participants who described accounting for each in their work. Table 8, which follows, provides a count of participants who cited previous experiences that informed their consideration of each factor, as well as a breakdown of the engineering and non-engineering contexts in which they reported having these influential experiences. All counts reported in this chapter are out 46, the total number of participants interviewed about their experiences solving complex engineering problems.

**Table 7: Categories of Factors, Definitions, and Count of Participant Mentions**

| Engineering Aspect Accounted For | Factor | Definition | Participant Count (n=46) |
|---|---|---|---|
| **Technical Considerations** | Technical Details | Consideration of technical details or aspects of a given problem | **41** |
| | Manufacturability | Consideration of how a particular solution may be constructed, assembled, or manufactured | **14** |
| **Immediate Conditions & Constraints** | Material/Financial Resources | Consideration of financial or material resources available or the material cost of a particular solution | **40** |
| | Project Timeline | Consideration of deadlines, the time available to complete a project, and/or time management for project | **28** |
| | Immediate Context | Consideration of the immediate context or setting in which a solution is going to be deployed, including setting, location, or rules or expectations immediately related to project outcome | **25** |
| | Provided Specs or Requirements | Consideration of requirements or technical specifications explicitly outlined in advance by customer, sponsor, teacher, etc. | **23** |
| **Stakeholders** | Stakeholders | Consideration of stakeholders and/or stakeholder needs or preferences | **20** |
| **Contextual / Social Considerations** | Future Considerations | Consideration of temporal dimension of the project related to the future, including future iterations or directions, sustainability, durability, etc. | **20** |
| | Environmental Impact | Consideration of the environmental impact on or of potential solutions | **11** |
| | History and Prior Solutions | Consideration of temporal aspects of the problem related to the past or what has been done previously | **11** |
| | Political or Economic Context | Consideration of political or economic aspects related to a problem, including regulations, government approval, or economic conditions | **10** |
| | Cultural or Social Context | Consideration of the larger social and cultural context in which a project is embedded and how it may shape or be shaped by solution | **7** |
| **Team Coordination** | Team Dynamics and Staffing | Consideration of team dynamics, relationships among team members, and/or the skills/knowledge/abilities of team members | **18** |
| **Interrelationships Between Components** | Interrelationships Between Components | Consideration of the relationships or interactions between multiple aspects or components of a problem or design | **17** |

**Table 8: Count of Participants' Experiences Informing Consideration of Factors, By Category**

| Category | Factor | Total Participant Count | Classroom | Project Team/ co-curricular | Internship | Work experience | Pre-college experience | Personal |
|---|---|---|---|---|---|---|---|---|
| **Technical Considerations** | Technical Details | 27 | 11 | 11 | 1 | 7 | 3 | 1 |
| | Manufacturability | 9 | -- | 2 | 3 | 4 | 2 | -- |
| **Team Coordination** | Team Dynamics and Staffing | 18 | -- | 7 | -- | 5 | 7 | 6 |
| **Immediate Conditions & Constraints** | Material/Financial Resources | 15 | 1 | 6 | -- | 6 | 3 | 1 |
| | Project Timeline | 11 | 2 | 4 | 4 | 3 | 2 | -- |
| | Provided Specs or Requirements | 7 | 5 | 1 | -- | 1 | -- | -- |
| | Immediate Context | 3 | -- | 2 | 1 | -- | -- | -- |
| **Stakeholders** | Stakeholders | 14 | 1 | 3 | -- | 9 | 1 | 4 |
| **Interrelationships Between Components** | Interrelationships Between Components | 8 | 3 | 3 | 1 | 4 | -- | 1 |
| **Contextual / Social Considerations** | Cultural or Social Context | 6 | 1 | 3 | -- | -- | 1 | 4 |
| | Environmental Impact | 4 | 1 | 2 | 1 | -- | -- | 2 |
| | Political or Economic Context | 3 | -- | 1 | -- | -- | -- | 2 |
| | Future Considerations | 3 | -- | 2 | 1 | -- | -- | -- |
| | History and Prior Solutions | 2 | 1 | -- | -- | 1 | -- | -- |

*Note: Total participant count based on number of participants citing any prior experience informing their attention to a given factor but some participants named experiences across multiple contexts so the sum of experiences across all experience types may be greater*

### *Technical Considerations*

The category of technical considerations includes the broad factor relating to *technical details* of a project as well as the factor relating to considerations of *manufacturability*. Collectively, these factors refer to the technical aspects of engineering work perhaps most broadly recognized, including technical specifications, analysis of data, issues related to technological systems, and the physical design and construction of models or products. Nearly all participants mentioned a consideration of technical aspects of a problem. For example, when describing his work on an automotive student project team, one participant described his team's consideration of a variety of technical factors:

> The first one was, like I talked about, with the engine height and the CG placement, versus the down force that we got. So we had to run some simulations of how things would change. Obviously, your cornering is gonna increase with the lowering the CG, it's also gonna decrease with your down force decreasing, which was like, yeah, they're related, essentially.

Another student discussed his experiences in an introductory engineering course, in which his team was tasked with building a blimp, explaining the structural considerations he took into account:

> The structural design of the gondola, we decided to have a lot bars in the bottom so we could just place the microcontroller embedded and such on there in whatever position because we didn't ... We needed to make sure that the weight was balanced so that it wouldn't tip up, but we didn't know where that would be, so we wanted to make it adjustable.

Given the breadth of the *technical details* factor and the nature of most of the engineering projects described, the fact that the vast majority of participants cited technological considerations is an expected finding. Though not specifically prompted to do so, most participants tended to describe technical aspects of their projects in great detail. Participants' depth of reflection related to these aspects is reflected not only in the frequency of which they were mentioned but also the length of their discussion of technical factors and level of complexity used when discussing these factors. Several of the participants who did not cite technical factors were working on non-technical engineering-related complex projects, though several participants working on technical problems did not explicitly discuss technical aspects of their work.

A smaller proportion, though still nearly a third, of participants cited considerations related to *manufacturability* in their projects, including what is feasible to design or build given technological, resource, and staffing constraints. For example, one student described her experiences in a medical device lab, grappling with the possibilities of 3D printing technology:

> And so, limits of technology and the 3D printing software, so we can really only do up to what our software allows us to do, which is a lot. But sometimes we're definitely limited by our software, especially because it's working in triangles and things like that. And if we were to make our meshes on our 3D software like super small so that it was more realistic, then we'd end up with prints that took two or three types as long.

Another student, discussing his experiences on a student design team, explained the ways manufacturability factored into his engineering work:

> So that's design for manufacturability of the frame and the jigs. If the jig is placed here, can I weld that part that's right next to where the jig is? And for the frame in general, if we've got two bars that are coming together at a very small angle, then what's that minimum angle that I can actually get in between the two bars and make a good weld? Then there are how far do these bars have to be from other parts of the frame?

Participants varied in the richness of their discussions of manufacturing considerations; while some participants made only a passing reference to the feasibility of building a particular solution, others went into great detail about the processes and constraints of manufacturing.

Participants described a number of previous experiences across multiple settings that informed their attention to the technical details and manufacturability factors when addressing a complex problem. These experiences ranged from formal educational experiences to professional engineering experience to pre-college experiences.  Interestingly, while 11 participants cited formal educational experiences informing their consideration of technical details, none described classroom experiences that informed their consideration of manufacturability in their work. I provide a more detailed description of the experiences informing each in the subsections below.

**Experiences Influential in Consideration of Technical Details**. Consistent with the fact that the vast majority of participants (41) described accounting for technical details in their work, the highest number of participants, 27, also described previous experiences that shaped their consideration of these technical details of their complex engineering projects. Eleven of those participants cited classroom experiences. One participant explained how her academic training helped in her work developing an adhesive, stating "I guess just some basic chemistry and intro to material science class about chemical attack or corrosion or whatever were useful." Another similarly spoke of the usefulness of her coursework for a project in the auto industry, stating:

> Oh yeah, as mechanical engineer like there are more courses in heat transfer sometimes you know about internal stability, you can do heat transfer analysis, you can do simulations to understand the heat dissipation and the layout to identify where you are going to put the other components at so it doesn't get heated up and you put it in a cool spot and you can use your knowledge where the cool spots are and the hot spots are.

Eleven participants also credited co-curricular experiences as influential in their consideration of technical aspects. Many of these participants described project team experiences, such as the experience described by one student, learning about a number of technical components for his automotive project team over the course of several years:

> I started with the low voltage safety circuits and I didn't really understand electronics all that well, but I was there and I was trying to learn. Took the first semester and I was doing mostly just the low voltage safety circuits with my mentor, and he was the one designing and teaching me as well. All of the different tests and design, and then different ... the whole process through design and implementation and testing along the way.

In addition to project team experiences, several participants described relevant research experiences. For example, a graduate student participant described how her prior research experiences guided her understanding of what might be important to consider explaining:

> So I, by that time, had worked for almost four and a half years in machine learning, and so had all the team members. But for each project, we know the points to be considered, but the consideration is completely different. So you don't know the answer, even if you have worked on something before.

Several other participants described relevant high school project team experiences as providing a technical background they were able to build on in their current projects. Participants also cited their professional (seven participants) and internship (one participant) work experiences in their consideration of technical factors. One participant who worked in the auto industry described how his early work experiences informed his later experiences in his role troubleshooting vehicle problems, stating:

> Going out there, as I said, doing launches, doing all these different things, just looking to problems and say, "Okay, what can we do to solve this?" And going back, I said, like first job I had, even though it was tooling, it let me learn all the tools, how the parts clamped together. And if this clamp goes first, this one goes second. And then, know which valves to go and all that type of stuff.

Finally, one participant described his personal efforts to stay current on various tools and software programs, and their usefulness in his projects, explaining:

> So since I'm interested, I myself keep looking for, like keep learning software through tutorials and things like that. So, there's a software that we use for finite element analysis in my [project]. So, I learned it on my own through tutorials. So, it helped in that way.

**Experiences Influential in Consideration of Manufacturability.** Nine participants described prior experiences that influenced their attention to manufacturability in their projects. Time spent working in industry, whether in professional roles or in internships, was a primary influence for seven of these participants. For example, one cited his prior work experience as contributing to his awareness about potential issues related to manufacturing, stating:

> So working as a supplier quality engineer, I was required to do manufacturer site assessments. […] And, it shows that you have a fully thought through what it takes to manufacture this product, in terms of any potential failure modes from a design perspective, from a process of actually manufacturing the design, or whatever the case may be.

Other participants gained experiences related to manufacturing in their high school projects (two participants) or their college project teams (two participants) that shaped their thinking in their current project. One participant cited considering the intersection of resources and manufacturability in both her current project in a medical model lab and her earlier experiences on an international medical project team, explaining:

> They're crossovers of like both projects in terms of being precise, and kind of the limits of the technology. In that case, we have the technology to do it here but we're working under the limits of technology in Nicaragua, whereas if we were to have the table manufactured in-country, what possibilities do they have to manufacture?

No participants cited coursework or personal experiences that informed their thinking about manufacturing in their projects.

*Immediate Conditions and Constraints*

This category refers to the most proximal constraints and immediate context under which a particular engineering project was addressed or deployed. The category includes the following factors: *material/financial resources*, referring to project costs and material resources available; *project timeline*, related to time constraints, project pacing, and how these inform solutions; *provided specifications or requirements*, which include any requirements or specifications provided at the outset of a project by a client, supervisor, teacher, or other stakeholder; and the more general factor, *immediate context*, which refers to the immediate conditions or setting in which a solution may be developed or deployed. In contrast to the types of factors I refer to broadly as social/contextual considerations, the factors in this category refer to those constraints and considerations most immediately and obviously related to the engineering project at hand. For example, while this category might include the cost of a particular project or limitations related to team budget and materials, the social/contextual considerations category may include financial-related considerations pertaining to economic conditions of or effects on the community or country in which a solution is developed, manufactured, disposed of, or deployed.

After the *technical details* factor, the four factors in this category were the most frequently described by participants in addressing complex engineering problems. The most commonly named of these factors, cited by 87 percent of participants as a factor in their project, was *material/financial resources*. These resources included project budget or funding sources and, less commonly, the equipment and tools available for addressing a project. For some, cost factored heavily into decisions, such as one student who described financial considerations related both to internal resources and keeping product prices down, explaining:

> I would say the cost factor has been something that we've looked at. For the nature of our project it is pretty costly, just because the material that we're working with is costly, 3D printing itself is coming down, but or license to our software is costly. So that is something we were trying to know to design our process within a reasonable cost budget, but also be significantly less than our competitor, which is a company that you just send your stuff to and they send it back to you.

In contrast, another participant reflected on how an abundance of resources shapes their workplace's approach to problems, compared to how they might have to work if budget were an issue, stating:

> Right now it's, we think about it more in the ... what's the saying in Facebook? Move fast and break things? […] It's an expensive way of doing it. We tend to do things that way. We want to fail early and fail quickly. But let's say money becomes a factor, we'd probably have to change things into a more conservative way of doing research that is a lot more thinking about things a little bit more.

With a few exceptions, participants identified material resources as a factor or constraint in their decision making related to a given project, but rarely discussed this in depth.

The next most common consideration related to the immediate conditions of a project was the factor *project timeline*, named as a factor by 61 percent of engineers in this study phase. Participants' discussion of project timelines often was fairly brief and most commonly related to the importance of meeting a particular deadline, determining goals for completing various aspects of a project, or the ways time constraints affected their work. For example, one professional engineer spoke of his experiences iterating rapidly on a project after being called in to address an issue a previous team was unable to solve explaining:

> And you don't have a lot of time because you've got to iterate really fast. This is something that ideally would have been nice to have two years instead of 11 months to do. […] So we arrived at [design decision] very quickly. Literally from the time I got pulled in until we made this decision, it was four or five days.

Another participant expressed her frustration when her company attempting, unsuccessfully, to stick to an unrealistic project timeline, which may not have resulted in the best solution:

> The timeline was a big one because we had an end date. It was supposed to be August of last year was when we were supposed to release and then those release dates are all coordinated with the other product releases that are going on throughout the year with this company. We ended up having to push our date back […] But the whole point was we've got to release, we've got to release. It's like we don't have anything to release with, but okay, we'll release. So that was an interesting consideration and time was huge for us. We really had to push and that was something they push, push, pushed on a lot, I think, to their detriment in some ways.

Half of all participants described considering *provided requirements or specifications* in their projects. This factor is likely to be very project-specific, as not all have well-defined specifications provided at the outset. In addition, participants may not always explicitly name a consideration of requirements, as the expectation that they address any requirements may simply be assumed. In some cases, requirements were part of a class assignment, as was the case in this student's introductory engineering course:

> The second one was that we had to use Gamemaker Studio 2, and that was just a constraint. That was like part of the class, because that's what they had asked us to do.

In other instances, professional engineers named certain rules in their industry that shaped their solutions:

> So contracting rules because those were hard and fast, and definitely a big component. We had to stay within the boundaries and oftentimes felt like constraints, but also felt like liberating knowing that as long as we stayed in these

> boundaries we can just do what we wanted to do. There was a lot of governance involved, which... kind of related to higher headquarters.

Finally, in our interviews, just over half of participants considered the *immediate context* in which their solutions would be deployed or the conditions of that setting. Aspects of the immediate context considered ranged from temperatures or other physical deployment conditions, rules and scoring of a design competition, employer policies related to work, or existing physical structures that shaped their work. For example, one structural engineer described considering a building's location and appearance relative to other nearby buildings, stating, "The biggest factor is making sure that this new building belongs in the whole setup of the downtown [City Name]." Another participant, working on nanoparticle systems for medical purposes, described accounting for how human bodies were likely to interact with the technology and the ways it shaped his team's design, explaining:

> Essentially, since we're using it in drug delivery, that basically tells us that our size is constrained to around between 50 to 200 nanometers. The reason for this is that essentially, your body has a way of filtering things that are bigger than this and smaller than this, and between it is that sweet spot where it won't be just automatically flushed out by your body, and it'll actually go in through like that leaky vessel thing I was talking about. So, your application kind of dictates.

Participants' accounts of the ways they accounted for the immediate conditions of their projects varied in depth, with some participants making only passing mention of such conditions while others discussed in depth how these conditions informed their decision making. Participants also described a range of prior experiences that shaped their attention to these immediate conditions of a problem. However, participants more often described relevant experiences that informed their attention to material and financial constraints and project timeline than other factors in this category. In part, the frequency of experiences related to these factors may reflect the fact that such financial and time constraints are common across a range of engineering projects and less specific to a particular problem. The subsections below provide a more detailed examination of the types of prior experiences shaping engineers' attention to the various factors in this category.

**Experiences Influential in Consideration of Material and Financial Resources**. Fifteen participants cited influential past experiences related to the ways material and financial resources informed their projects. Only one participant described a relevant course experience as shaping her thinking in this area, describing similar requirements in his project-based introduction to engineering course and his transportation-related design team project. He explained, "I have a very fixed budget, in terms of what I can work with last semester. I think it was like $100. So obviously, it's just like slight changes but ultimately it's still very similar." Six participants described prior project team experiences. For example, one student described her past role on a student project team as informing her attention to cost in an aerospace internship experience, saying:

> Cost for sure. A lot of my rocketry projects, we got very limited funding if any funding from the school. So most of it was, "Can we scrape together enough money to build a rocket that will fly?" And I had been treasurer for the group too, so I was very conscious of the cost aspect.

Several participants described high school project experiences in which they had to consider material resources, drawing parallels to their current project team experiences. As Tyler explained, "…budget, same type of deal." An additional six participants described professional experiences that informed their attention to resources in their current projects. For example, Alvin credited his previous consulting work, stating:

> I think without my working doing consulting that I wouldn't think about things as much related to cost in change management. Those were things that got brought up a lot when I was consulting, is primarily consulting with large administrative leaders at systems. And so, they worry about those things a lot more than me in my engineering role that I would've worried about. So I think that those were on my mind a little bit more than they probably would've been otherwise.

Finally, one participant drew parallels between her current project and her childhood experiences budgeting for a party and optimizing resources on her project team, explaining:

> I get a budget from my parents to create a party for my brother. This actually happened. […] So, that's when I began to learn how to manage myself within a constraint. So I was given, like $50 and I had to get balloons, cake, and all this stuff. And that's when I'm like, "Okay. How do I organize this and where do I find the best prices, but I also don't want something cheap." I want something that's like ... maybe the balloons can be cheap, but the cake has to be good.

**Experiences Influential in Consideration of Project Timeline.** Eleven participants described prior experiences that informed their consideration of project timelines and time management, citing classroom, project team, internship, professional, and pre-college experiences. Two participants described classroom experiences, related to meeting requirements by due dates, which informed their attention to time constraints. One student explained, "…and in classes. You've got a test on this date, you've gotta understand the material. It's not as in depth or anything, but generally you know you've got this problem, it's gotta be solved on this date." Two participants described high school robotics team experiences and an additional four participants cited co-curricular activities in college. For example, one described her experience participating in a Hackathon, which raised her awareness of time constraints in her course project, saying:

> For time constraints, I can think back to my hackathon experience because that's, it's just like 36 hours. There's always so much you can do during that time. So we developed the base of our project, but obviously we didn't get to finish it because it's not so much we can do in that time period. So, it relates to that.

Another participant spoke of needing to balance multiple demands, between project team experiences, course requirements, a family business, and other extracurriculars, drawing parallels between his personal decision making and his project team. He explained, stating:

> So same thing in a business, same thing on the team. What are the current issues? What needs the most attention? How could we shift and reprioritize all of our

> tasks to spend the time where it matters most? And when we're doing that task, what are more efficient ways of accomplishing it?

Finally, a number of participants described impactful experiences in their internship (four participants) or professional (three participants) work experiences. One described developing time management and planning skills in an internship experience, explaining, “So we basically sat down at the beginning of the summer and we're like, "Okay, here's our weekly plan. This is what we're going to accomplish this week." So by week three, I was pretty much working on stuff all by my own because we had set out this plan.” She contrasted that experience to her current research experience in which she received little guidance on timing and project management, saying “it wasn't as structured as I maybe would have preferred looking back. So I think now I know that I need to set those plans out in order to be successful.”

**Experiences Influential in Consideration of Provided Specifications or Requirements.** While attention to provided requirements or specifications was something a half of participants (23 of 46) explicitly mentioned in our interviews, only seven described prior experiences that informed their thinking about these given requirements. Given the inherently project-specific nature of provided requirements, it is possible that few participants felt it was necessary or relevant to draw on past experiences to attend to them. The majority of participants (five of six) who did describe prior experiences as influencing their attention to provided requirements were undergraduate or master’s students. These students described an understanding of the importance and process of accounting for provided requirements stemming from their coursework experiences. For example, one undergraduate student described what she learned throughout her academic experiences:

> Basic school projects. You have all these constraints for school projects like you have to meet these requirements. A paper: it has to be this long. It has to include this. It has to be this font. Everything like that. […] Just having that experience with constraints. Constraints was  something you always have to keep in mind

> when you do projects like this, 'cause if you mess up something and the person's like, "Okay, that's not what we asked of you." If you build your robot too high or if you make it over the specific weight requirement or something like that. You always have to keep constraints in mind. When you come up with any idea like, "Oh, we should do this. Does it meet the constraints?"

Other students described academic experiences related to tests or other assessment criteria, with one explaining “If you don’t answer the question, then it’s wrong. So, I think that has to do especially with client feedback.” The professional engineer who described prior experiences in this area spoke specifically of previous work for the same client, and an existing understanding of his client’s requirements.

**Experiences Influential in Consideration of Immediate Context.** Though a majority of participants (25 of 46) mentioned accounting for the immediate conditions in which their solution would be deployed in their problem solving, only three mentioned prior experiences that informed their thinking in this area. Two participants mentioned prior project team experience with close connections to the problem they described in our interview. For example, one discussed his experiences in the prior year’s competition for the same auto team to learn about how to better tailor the current year’s vehicle to score highly based on the rules of the competition, explaining:

> After last year's performance, we realized, "Okay, we're obviously a high-performing team, 'cause we got fifth in the race, but we are not high-performing as the top team, obviously, performed better than us, so where is the disconnect between us and them?" […] They published the scores, so you can see exactly how you stack up to, compared to the other teams. And so, when we saw we were getting half the points they were in certain events, we were like, ‘Okay, this should be a red flag. That's what's holding us back from essentially performing on their level.’

Another participant, discussing her work developing a prototype of a military vehicle, cited prior internship experiences in which she tested vehicles in different weather and temperature conditions that she translated into her current project. She explained:

> So I'd be in the climate tunnel. It was really cool. They have, it's at where the lights can track at different times of day and see where it affects the car and there would be like a polar vortex and like… 'We should probably see if this part's gonna break in the extreme heat or if like a touch of water hits it, it's not gonna work.'

Given the highly contextualized nature of the immediate conditions in which any given solution may be deployed, it is perhaps unsurprising that few participants identified prior experiences that translated into their current project and, for those who did, cited experiences very similar in nature.

*Stakeholders*

The next most commonly described factor in participants' decision making when addressing a complex engineering problem was the *stakeholders* affected. About 43 percent of participants described considering stakeholders of any kind in what their approach had been to solving a complex problem in which they had engaged. While I define stakeholders broadly, including clients, users, beneficiaries of a project, individuals overseeing the work, and anyone directly or indirectly affected by a particular project, the majority of participants spoke about only the most proximal stakeholders, such as clients or future users of a product. For some engineers, a consideration of stakeholder perspectives centered prominently in their decision making, such as one student involved in an introduction to engineering course project in which they were tasked with developing a video game for a visually impaired client. She explained:

> Also a big thing was making sure we were appealing to our client. So the girl that we were working with, that was actually something that our professor kind of applauded our group on a lot, was our ability to kind of work with her, and how closely we were trying to kind of make sure that our design process was reflective of what we had. The feedback that we had gotten from her, with initially meeting her and kind of hearing her interests, and things like that.

While the majority of participants spoke of the most proximal stakeholders, several described a broader network of stakeholders whose interests factored into their decision making. For example, one senior engineering faculty member leading a new education initiative in his university described a number of stakeholders, explaining:

> So department and the chairs then are important stakeholders. The College of Engineering in general have all kinds of student teams that this is an opportunity to get them engaged as well. So the question then becomes, for instance, is it important that all students engage in this course. Are we just supposed to be serving those students that come in and they're very uncertain?

Approximately 30 percent of participants cited prior influential experiences related to the importance of considering stakeholders, described in further detail below.

**Experiences Influential in Consideration of Stakeholders.** Though fewer than half of participants mentioned considering stakeholders in their work on a complex project, 15 of these individuals described impactful prior experiences that shaped their attention to stakeholder needs and perspectives. Of these 15, nine participants cited meaningful professional experiences as an influence. One participant, who described a project in engineering education, described his previous experience as a university lecturer as informing his understanding of student needs and preferences. For example, he said:

> We know the students ... and it's something that it still impacts me a lot, I know that it is happening right now ... is they are not going to look into textbooks anymore. They don't like textbooks, they don't want to go to textbooks. So how can we do something that helps them also have the material, but also make it interesting for them to go and see?

A number of other participants described prior work experiences in industry careers. For example, one individual who previously co-founded a successful startup and was now working as a consultant for other startup companies, described the critical role of her prior experience in understanding client priorities:

> By having done the startup experience myself and going through that whole process, it allows me to have a really unique way of interacting with the clients and with their projects. I have very, very, very little big industry experience so I don't come from a field of people working in cubicles and unlimited resources. [..] Every role, every resource, everything has to be highly efficient and highly

> focused and so I think that, coming from that experience and then coming into a consulting role for particularly startups really allows me to work with them in that manner.

Several other participants described project team experiences as influential in their consideration of stakeholders. For example, one explained:

> I mean I think definitely appealing to the client was something that I wanted to try to keep in mind. That's also something I'm thinking a lot about with me [Name] project team right now. Because I think I heard a lot and learned a lot in the past about ideas that may be seemed great, but then they weren't very conscience of the audience that they were kind of tailoring it to. Especially when the audience was vastly different, or that the client was vastly different from the engineer.

Four participants named personal experiences that shaped their attention to stakeholder needs. One engineer explained that, as someone from a minoritized background, he felt he learned to be more empathetic to the needs or perspectives of stakeholders, stating:

> Also being from somewhat of a diverse background, I always tend to lean more to an empathetic, with compassionate view to other people's points of views. Their perspective of where they're from. I think that, that allows our voices to be heard at the round table, and definitely I think to address them.

Only one participant, who named a number of other impactful experiences, described any classroom experiences related to the consideration of stakeholders, describing having had several speakers come into her introductory engineering class. She said:

> And we did have speakers come in occasionally in our class, which was sometimes cool. And we had people from [socially-engaged design center] come in and kind of talk to us. And it just made me think, "Okay. Our point is not to make something that's really cool. Yeah, that's part of it, but our point is to satisfy the needs of our client. And sometimes we have to give up what we would necessarily want to make sure that we're doing the best job for them.

*Contextual / Social Considerations*

This category includes five factors, all referring to the less immediate aspects of an engineering problem. While many participants' descriptions of their thinking related to the factors in this category related to the larger societal or human impact, not all are explicitly human-oriented. Rather, these factors are grouped together on the basis that they broadly relate to the “bigger picture” of how one’s engineering work is situated in time, environment, and society. These factors include *future considerations*, including future iterations or directions of a project or the longevity of a particular solution; *history pertinent to a problem or prior solutions* on which engineers may build; the *environmental impact* of or on engineering solutions; the *political or economic context* including, regulations, government approval, political responses, and societal economic conditions; and the *social or cultural context* in which a problem is embedded, including cultural beliefs, practices, and impacts.

Of the contextual / social considerations, participants in the study most commonly described accounting for *future considerations*. Approximately 43 percent of participants mentioned this factor. For some participants, this included considering the future directions of a particular project and how it might be built upon in the future. One participant, working in an applied research lab explained:

> I guess future use of the project has been something that we've kept in mind. We do eventually want to take this and create a small business out of it, so kind of making sure that it continues at a feasible level. And also, we'd love to take models from different departments and that's something that we've thought of as you know, "Can we do ortho? Can we do a bunch of different things?" But for now, we're kind of keeping it on the small scale because we don't want to explode too quickly.

Another participant, developing new materials for aerospace uses similarly talked about the future implications of her work:

> Probably the future use of the design. Because I was always looking for right now we're working on the very, very small scale. But years in the future if this has been proven strong, that could impact the design of airplanes and spacecraft in the future. So definitely that.

While this factor was more frequently named compared to other contextual factors, it often came up in interviews only after explicit prompting about other factors participants may have considered. Generally, participants discussed future considerations in little depth; they mentioned the importance of durability or longevity of a particular product, or acknowledged hypothetical future iterations. As one participant explained, “once the whole project is complete,” her team “would have thoughts about how future uses work… and who can actually benefit from it,” but that these considerations were not at the forefront of their decision making while working on the project.

Other contextual factors, such as *environmental impacts*, were less commonly discussed by participants as things they considered in their complex engineering projects. Less than a quarter of participants described any consideration of the impact of or on the natural environment. One participant, whose work developing a new a way to produce biofuels had longer-term environmental implications, described having to balance safety concerns with the short-term environmental impact of their project. He explained that, in the developmental stage, they decided burning any biofuel produced was the best immediate solution balancing these two factors:

> It's very interesting because of a lot of safety concerns. This is when it gets into the environmental versus safety considerations. In our first prototype, we had to actually vent whatever biogas we were producing. That was because it was... We had this in a lab setting, and flaring it was probably the best environmental thing we could have done.

Another participant, working on a student project team with an international sustainability focus, described the environmental tradeoffs of traveling internationally to do research for and work to implement their project, stating:

> I guess it's like when you look at how much fuel, when you look at the impact of flying to India and back, we will only create if we can only send as many people as we are saving that energy. So if we aren't gonna have enough of an impact, are we just doing more damage to the environment by sending more people and so that's a really hard thing to outbalance, it's crazy when you look at flights.

Similar to future impacts, environmental considerations often came up after prompting in our interview. Few participants who mentioned environmental considerations discussed these in depth. Several acknowledged when prompted that they recognized environmental implications of their work but felt constrained in their ability to actually account for these in their work due to budgetary or regulatory requirements.

Similarly, less than a quarter of participants described accounting for *relevant history or prior solutions* in addressing a complex problem. For example, one student involved in an aerospace student project team described the importance of researching prior solutions, in order to ensure his team did not repeat past mistakes in their work. He explained:

> Seeing what people have done in the past is very important. So much of my research this summer on injectors has been from old MASA papers. They've had a lot of success and they've had a lot of failures. Reading the hundreds, and hundreds of pages that are dedicated to describing those failures and successes is very important in not making the same failures twice. So if someone has already made the same mistakes that you're about to make, it's always good to catch that.

Another participant, who was working for a civil engineering firm involved with restoring old buildings, described the importance both of his prior experience working on that building as well as understanding how, historically renovations had been done and the potential risks associated:

> Well, I mean, having worked on the building in 87' through 92' I already knew that what was important. I worked on in 87' to 92' when we started taking the building apart to get rid of some of these floors, they'd added in between floors and we can basically gutted it where there wasn't historic murals or something on the wall that were still extant. The people had over the years put openings through the wall, they even put a door through a wall here and then they changed their mind and put another years later they put another door. [...] So that was one thing that I already knew was going to be coming up that if they're going to be putting in new openings, we have to make sure if they're going to abandon other openings that they're not going to use because they're moving the duct work over here from there or moving a door over here from there that we close off, we properly infill the openings with new masonry that mash the existing so that we don't rob the building of its strength.

Participants almost never discussed this factor in depth, with most responses reflecting a passing mention of ways their team looked to previous solutions or designs to inform their work. The two exceptions to this limited reflection came from experienced professional engineers, including the civil engineer quoted above, who discussed projects that built on their own earlier work on the same product or design.

Approximately a fifth of participants described accounting for the *political or economic context* in addressing a complex engineering problem, most often pertaining to national policies or regulations. For example, in discussing his lab's consideration of the types of medical issues and interventions to address in their work, one participant described the ways the federal government incentivizes researchers to focus on particular area, explaining:

> So the US government said, "We're going to give these incentives to pharmaceutical companies, and we'll also loosen pricing." And you're left with something like CAR T-cell therapy, where the regulatory aspects were lowered. There's tax breaks that are involved when you're making these type of drugs, and then you can give them ridiculous pricing.

Another participant, working on an aerospace project near the norther U.S. border explained that his group had to secure permission to use Canadian airwaves as part of the logistic hurdles in their work:

> The political was interesting. We have a radio system on board and because here [in City Name], we're so close to Canada, we have to get permission from Canada to be able to use the radio when it's come to.

Like several other contextual factors, political or economic considerations often came up only after explicit prompting. While the majority of mentions of this factor were relatively surface-level acknowledgements of regulatory policies, several participants, like the individual quoted above describing U.S. government funding policies or another working on developing new charging standards for electric vehicles, described the impact of political factors in depth. Notably, the influence of, or impact on, broader economic conditions was rarely mentioned.

Of all factors identified in my analysis, the least commonly described consideration was the *social or cultural context*. Only 15 percent of respondents described this as a consideration in their description of solving a complex engineering problem. However, several participants described this cultural awareness as something that distinguished their work. For these participants, considering the cultural context meant seeking to understand the way of life of stakeholders in another country to ensure their team’s solution reflected the actual needs and lifestyles of those who would be using their product. One participant explained:

> And so that is something I'm honestly very proud about our project is that we spend so much time thinking about the cultural ramifications and for these women, so much of their identity in their entire life they've been cooking one way. So how do you come up with a way to tell them, no, that's not the right way and do it this way? Because a lot of the times what happens with technology is it just never gets used.

Another participant, however, viewed the cultural context as a local consideration. In describing his work developing a new system in a healthcare setting, he spoke about how critical it was for his team to consider the hospital’s cultural norms so that their solution would be accepted and useful:

> So I think that making sure as we're thinking about this design too that it is gonna fit into the cultural norms and will be accepted. So having something like ... I mean, there are constraints as far as nurses can't sign off on orders that a physician might be required to, but also just having a nurse superseding a physician in any way that they're interacting in the system too, is something that we look into and consider as we're designing.

Although cultural or social factors were the least commonly named factor and more commonly arose in interviews after explicit prompting, those participants who mentioned cultural factors (both with or without prompting) generally discussed them in some depth.

Just as many of the social/contextual factors were among the least often cited in engineers' approaches to solving complex problems, these were among the factors that participants' least commonly identified prior experiences that informed their attention to such aspects of engineering work. In addition, few participants named classroom or workplace experiences relating to social/contextual aspects, more frequently citing experience in co-curricular activities or their personal lives. These experiences, organized by factor, are discussed in greater detail below.

**Experiences Influential in Consideration of Future Uses.** Only three participants of the 46 interviewed described prior experiences that informed their attention to future applications or use of an engineering solution. Of these, two participants described project team experiences that influenced their thinking about the longevity of their designs. One participant explained:

> Our chapter was really, really concerned with after we leave, is this just going to fall apart? And we really, really didn't want that to be the case. So a lot of our trips back to [Country] were ... They didn't deal with design or construction at all. It was all about maintenance, and it was all about building relationships, making sure that the people that said they wanted to work with us continued to work with us and that they were satisfied with the ideas that we were presenting to them […] So I really try to think about those aspects. I think that really was imprinted on me.

One other participant described his prior internship experiences working on a biodigester that informed his thinking on a similar project in school and long-term risks of such a project, stating:

> The company I was working for was going to be the owner and operator of the bio-digester. It was very important that certain safety considerations were made. There was a lot of debate back and forth with [Organization] because they wanted to do some things a certain way and we're like no, that's a big safety concern for us. You know, 15 years down the road, we might have corrosion issues, and that could lead to a leak.

No participants cited academic or professional work experiences influencing their consideration of future-related aspects of a problem.

**Experiences Influential in Consideration of History and Prior Solutions.** Only two participants described experiences that informed their attention to previous solutions or relevant history. Both spoke specifically of learning from what others had done previously. One described his coursework experiences as informing his focus on seeking out prior solutions to inform his work on his project team, stating:

> For both schoolwork and like this, of, as far as a professor gives you old projects to look at. It seems like that always helps. And if you know kind of what you're doing before you have to do it, you typically do it a lot better. So if you're looking at a cutter design, go look at a cutter that NASA made because they probably did it pretty well.

In his role as a professional engineer, a participant described learning on the job and from his peers, about the importance of looking to prior solutions. He explained that he now encourages his team members to do the same, stating:

> The main thing I tell my folks now is I don't want you to invent if you don't have to. Because we have things that work, so it's a matter of trying to reuse proven engineering solutions. And if there's something that's not working and we didn't reuse a proven engineering solution, why didn't we? And what's it going to take to make this design change? […] Over time you kind of pick it up. You absorb as you go along. It's one of those things where you may think you're a good problem solver, but being an innately good problem solver doesn't always make you the expert in solving the problems. You learn from your peers too.

**Experiences Influential in Consideration of Environmental Impact.** Only four participants cited experiences that informed their thinking about how to account for environmental factors in their engineering problem solving. Two of these participants described the influence of sustainability-focused project team experiences in international contexts as influential in their thinking about environmental factors. Another participant mentioned environmental awareness being a chief emphasis on their internship experiences in industry. When asked about big influences on her thinking about her project, one answered: "Probably from my time at [employer names]. Probably environmental, was probably the biggest one because I did a lot of environmental testing with the radiators." Another participant, who was also heavily involved in an international project team with an emphasis on sustainability, spoke of an elective course on sustainability that emphasized the “three spheres of sustainability […] society, economy, environment, how they all interact” as also informing her thinking about the topic. Finally, two participants cited their personal experiences growing up as a key influence on their attention to environmental aspects of a problem. One explained that environmentalism was a core family value for her growing up, while another participant cited his experience as a child of immigrants from El Salvador, and his experiences visiting the country as a child as key in his decision to pursue environmental engineering work:

> Something that always stood out to me was the fact that a lot of the people there didn't trust the water. And I think that ... Seeing this unequal distribution of portable water, because going from a very prosperous country to a resource poor country, there was a glaring difference. And I think that's what made me start to think of more of the societal impacts and how do we think about these solutions in an equitable fashion.

**Experiences Influential in Consideration of Political or Economic Conditions.** Only three engineers interviewed cited any prior experiences that informed their attention to political or economic factors, ranging from governmental regulations to the economic strength of a particular community. One participant cited her experiences in a sustainability-oriented student project team as introducing her to the importance of considering legal standards and regulations but that they were more important in her current role in the auto industry, explaining “standards and regulations, those sorts of things we thought about, but I don't think, being a student project team, those weren't the core things.” The other two participants who described influential experiences related to their thinking about political and economic considerations both described personal experiences. One professional engineer who worked in the medical device industry, explained that his experience reading theological texts to discern meaning helped him comprehend regulatory language and how it might apply to his own work. He stated:

> And so having an interest in philosophy and I have interest in theology from a Christian background of like, "Okay, I've got this text that I have to understand of why it exists, and what it's trying to say, and the purpose for why it was written." And so to take... Bringing those skills into reading the regulatory side of things, I'm like, "Okay, this was written for a reason. Can we dig into the understanding of why it was written." And then to use that understanding to inform decisions we make from an actual day-to-day development work side of things has been a big part of my thinking for things.

Finally, the participant whose childhood experiences in El Salvador were described previously related to the ways they shaped his thinking about the environment, described the economic and societal conditions that related to this and shaped his focus as an engineer. No participants described any classroom or work experiences as influential in this way.

**Experiences Influential in Consideration of Cultural or Social Context.** Six participants spoke about experiences influencing their attention to cultural/social aspects of an engineering problem. Several participants cited participation in an internationally-focused engineering co-curricular or project team experience. For example, one graduate student participant described his previous experience in Engineers Without Borders as a key influence:

> So the whole managing a project while I was in Engineers Without Borders in undergrad, that taught me a lot of how to deal with people. It was an international project, so it taught me about grants and how to talk to people about this is what we want to do and how to explain it. It taught me a lot about how to deal with people from different cultures or how to leverage the fact that I'm from Columbia and we were working with people in Ecuador, of how to leverage those type of things.

Participants also cited personal experiences as informing their attention to cultural issues, including experiences related to their family background or values. For example, one explained that her family prioritized exposure to multiple cultures and perspectives, stating:

> I just grew up in a family that really push diverse perspectives and not just going with the flow. And I think especially my parents made me take a year off and travel because they said that I didn't have a wide enough perspective on the world, which I'm very lucky for.

Thinking about the role of culture outside of an international or unfamiliar context, one engineer working in the tool industry described her personal experiences as a woman undergraduate using the machining shop and her discomfort in that space, as well as the larger culture around women and tool use as something that shaped her understanding about potential cultural barriers to tools being marketed to and for women, explaining:

> There's this huge barrier to entrance in using hand tools that men just don't experience or don't understand. Especially white men who are in a middle class environment or a rural environment where they grew up on a farm and it's just part of their life. There's no barrier there for them to just pick up a wrench and just start yanking on their plumbing pipes. But a woman, in my experience, it's not a natural oh, yeah, I know what tool I need to fix that and I know where to get that and I know how to do that. […] That's just not the culture, but there's no reason that it couldn't be and I think it could be a really empowering opportunity for a company like this one to take, you know what I mean?

Notably, only one participant mentioned any formal educational experiences as informing their decisions to account for cultural or social aspects of an engineering problem. One student, who had also sought out relevant personal work and international project team experience, described having guest speakers from a socially-aware design center speak in her undergraduate course. No participant cited any professional experiences as informing their attention to cultural or social implications.

*Team Coordination*

Team coordination, or *team dynamics and staffing*, is a category that refers to participants' consideration of relationships and efforts among their team members, classmates, or colleagues to address an engineering problem. This factor is categorized separately from other human-centered factors in that it emphasizes internal dynamics and communication as groups work together to address a problem, rather than considering external others potentially affected by the problem. Approximately 40 percent of participants cited team coordination as a consideration in their approach to solving a complex engineering problem. In some instances, often within student project teams, participants described the role the skills and attitudes of team members can play in the success of a project. For example, one student explained his concerns around these dynamics:

> Yeah, the team culture is ... like I'd said, some people last season were very done with it. It hurts work ethic when you're not feeling like this is what you want to do and when you're seeing other people that don't want to do it. It hurts motivation. Do you want to work with those people? Are you friends with them?

Other participants described strategies for working effectively in teams, such as one senior engineer who described his emphasis on communication when managing an engineering project team:

> So I learned that early in my career, so I always laid out what I called the communication plans that would be with the team doing the work. And then all the way up the management chain on both the customer side as well as the [Company] side. And that was a very conscious plan that I laid out. And again, engineers typically don't think that way. It's more technology jump in and solve the problem, solve the problem. But when you're managing a bunch of technical people and especially complex problems, which sometimes are hard to convey the depth or the real issue, the communication becomes really important.

**Experiences Influential in Consideration of Team Coordination.** Eighteen participants noted experiences that influenced their thinking and decision making around project teams as an aspect of their engineering problem-solving, including a consideration of team dynamics, interpersonal relationships, and the skills and knowledge of team members. Seven undergraduate engineers cited prior high school team experiences as informing their consideration of team-related factors in their problem solving. These high school team experiences included group projects, sports and academic teams, and high school robotics teams. For example, one described the foundation provided by his high school team experiences:

> And even just some of the basic things, like working with peers, learning to work with the team. And that's something I've always thought, like I am a good team member. I've been a part of tons of athletic teams and stuff like that growing up, and Science Olympiad teams, and school math teams or whatever it is.

Seven participants cited other college project team experiences as important influences. One undergraduate student heavily involved in a student project team explained that his role as project manager on a prior project team prepared him to account for team dynamics, stating, “I took away so many learnings as a project manager on interpersonal relationships, and how to manage a team.” Among professional engineers, five cited their prior work experiences as informing their attention to team-related factors. Several participants named experiences where things went wrong as raising their attention to team factors, while others cited positive experiences and training. One participant spoke of the influence of her prior military training in this regard, stating: “Certainly I think, the people decision, that's something that we learned in the military from day one. We're constantly trying to... it's like a leadership laboratory. I think bringing a bunch of people to accomplish a vision comes very natural to the military leaders.” An additional six interviewees described personal experiences that shaped their attention to team aspects. One participant described his experiences coaching his children’s basketball team, another spoke of a family business, and another spoke of learning from the practices of his mentors. Another described his experiences growing up in a community faced by crises that required frequent collaboration as shaping his affinity for teamwork and understanding of its importance. He explained:

> So basically I have always been a team player. So if the team is performing, like I said that we had only one month to build that car after it got breakdown, so we work night and days for that and everyone was, without complaining, everyone was working. So if that is atmosphere, then ... that is what I like. So if that is atmosphere, then come what may. You can solve any problems. And I am from a city called [Name]. It has a history of many calamities. So I always see teamwork there. So whenever I find a team, I am really excited.

While many participants spoke of experiences that informed their attention to teamwork, participants generally described these experiences in broad language, without providing specific examples.

*Interrelationships Between Components*

When confronting complex problems, being able to account for relationships between various aspects or components of a problem is a key skill. Approximately 37 percent of participants explicitly described accounting for such *interrelationships* in their work. This factor, in its own category, is distinct in that it pertains to relationships rather than a particular component of an engineering problem and its context. Many of the participants who described accounting for such interrelationships focused on the interrelationships between two technical details of a design. For instance, one engineer working in the auto industry described these interrelationships and their role in vehicle design, stating:

> So, since the chassis has interaction with every single other component, powertrain, cabin, axles, so there was a lot of integration and communication that needed to be made. So, we have a person called a vehicle integrator who makes sure the geometric packaging is ... like nothing is interfering, or everything is where it should be, at its right place. So, there was a lot of interaction in terms of that. So, making sure the clearances between different parts are right. Structurally also it should be good, so we can't, like, increase the weight.

Several participants spoke of interrelationships more broadly, beyond strictly technical details. One participant, also in the auto industry drew a visual representation of the factors she considered in her approach to problems, drawing arrows between a wide range of factors in effort to demonstrate the complexity. She explained her perspective:

> But all of that connects to these different things. So, all of these different, which I guess is where all of these arrows, they kind of go all over the place. There's probably arrows that I'm missing on here, for sure, but they impact each other. So, it's more of an ecosystem of factors, as opposed to a list of factors, which is probably why I drew it this way, as opposed to a list.

Though fewer than 20 percent of participants mentioned influential prior experiences than informed their attention to interrelationships between various factors in an engineering problem, those who did cited experiences across a range of domains.

**Experiences Influential in Consideration of Interrelationships between Components.** Eight participants described experiences informing their attention to the interrelationships between project components in the engineering problems that they described. Five of these participants cited professional work experiences as key in informing their attention to these interrelationships. For example, one described her experiences doing a rotation in an auto plant as influential to her understanding, stating:

> And so, meeting all of the folks at the plant and seeing what they do every day kind of puts into perspective, "This thing has to be manufactured. What do you want to add into it?" So then there's a whole team of people that have to assemble it and put it together, and then there's a whole subsystem of parts that have to come together. So, you have to figure out how to code and make sure everything shows up at the same time, so that you can assemble it in the correct order, and that it gets shipped appropriately, to the right location.

Several other participants named their project team experiences, including high school robotics team experiences and internationally-focused design work as influential. Three participants described course experiences informing their thinking about interrelationships between project components. Two of these participants described a focus on complex interrelationships to be relatively central to their education. For example, a Master's student with a background in Chemical Engineering, said:

> Basically, in all of these different courses, and I could give an example in each course, you can have a very complex problem, the equivalent to what you might see on an exam for example. […] It's something that has so many different components and things that you have to think about. Being able to read it through once, then read it again and absorb what is being asked... I'd say reading it a third time and being able to be like okay. This is what I need to do. I need to do A, B, C through F before I can get to X, Y, Z.

However, another student cited only one course on sustainability in which such interrelationships were emphasized, and another explicitly said that, while accounting for interrelationships between project aspects was something she learned to do in her personal design work, this was not something emphasized in her formal education.

**Summary of Findings**

Examining the types of factors to which participants explicitly described attending when addressing a particular complex engineering problem revealed substantial differences in the number of participants who attended to various aspects of the problem. Notably, participants most commonly mentioned the *technical details*, and more proximal conditions surrounding a given problem, such as *material resources*, and *timeline* of a given project. With the exception of *future impacts*, the factors categorized as social and contextual, including the *cultural*, *environmental*, and *political or economic* context, were the least likely to be described as considerations by participants in their work addressing complex engineering problems. To begin to understand what shapes engineers' attention to various factors (acknowledging also the varied nature of project types), I analyzed the experiences that the engineers in this study cited as influential in their thinking about these various factors. Table 8 near the beginning of this chapter provides a summary of the total number of participants who mentioned a prior experience that informed their thinking related to a particular factor, and the nature of the experiences that participants cited as influential for each. Notably, the most engineers described experiences related to *technical details* of their projects, as well as internal *team dynamics*, and immediate conditions such as *material and financial resources*. The fewest number of engineers described influential prior experiences related to contextual aspects of an engineering problem such as a consideration of the *cultural or social context, environmental impacts*, the *political or economic context*, *and future and past-related considerations*. Across all factors, with the notable exceptions of attention to *technical details* and *provided specifications*, few participants named engineering coursework experiences as influential. Rather, for many factors, our participants described co-curricular activities (primarily student project teams), and internships or professional work experiences as informing their thinking. Participants were most likely to rely on their personal (non-academic or professional) experiences in informing their thinking about people-related and contextual factors such as *team dynamics*, *stakeholder needs*, *cultural/social context*, *environmental impact*, and the *political or economic context*.

### Key Insights

Findings from this chapter point to several key insights related to the ways an underemphasis on social and contextual aspects of engineering work may be reproduced through the day-to-day practice of engineering work. If engineering work is defined by and learned through what engineers actually do as part of their regular engineering practice, it stands to reason that this day-to-day practice, rather than top-down calls for change, holds more influence in the extent to which the field of engineering embraces a consideration of factors beyond the purely technical. Chapter 4 highlighted the fact that many engineering students and practitioners perceived social and contextual aspects of engineering work to be underemphasized in the engineering contexts in which they engaged. In this chapter, which examined data from first phase interviews with the larger pool of 46 participants, most participants' own practice seemed to also reflect, and possibly perpetuate, this underemphasis on social and contextual aspects of engineering work. Despite asking participants about their experiences solving complex problems, which ostensibly require attention to a wide range of factors, a minority of participants described accounting for a range of contextual factors including cultural, political, economic, temporal, and environmental considerations. Further, they often did so after explicit prompting. Although many participants cited environmental, political/economic, and temporal considerations, they did not often elaborate in depth on these factors, particularly compared to the level of detail and nuance demonstrated in their discussion of technical factors. The few participants who described accounting for the social or cultural context in their work typically discussed these in depth, but again, many needed to be first prompted to elicit a discussion of these aspects. It is possible that these participants were uncertain if a discussion of cultural considerations was relevant in an account of their engineering problem solving process. Alternatively, these factors may not have been at the forefront of their minds. Both, possibilities would nonetheless be telling demonstrations of how engineering cultures shaped participants thinking about what is and is not relevant to engineering work.

The broad pattern of less frequent, and less detailed, consideration of contextual factors by participants suggests engineers' practice is serving to perpetuate narrowly defined images of engineering work. It also raises questions about why these engineers devote less attention to contextual aspects. If social and contextual dimensions of engineering work are not widely valued or recognized as legitimate, engineers will be discouraged from integrating them into their own practice as doing so runs counter to the most immediately valued, recognizable ways of presenting oneself as an engineer. Certainly, the factors mentioned by participants are a function of the nature of their projects, which ranged in topic and scope substantially; not all the factors identified in the interviews are relevant to all engineering projects (for example, manufacturability is unlikely to be a concern in computer science engineering problems). Still, it is notable that so few participants described projects that they felt necessitated a focus on these contextual aspects of engineering. Also important is the fact that participants least frequently described having influential prior experiences related to contextual aspects of engineering problem solving, suggesting they had little prior experience on which to build in these spaces. This was particularly true of the classroom and professional settings, which represent the core of engineering training and work, as few engineers cited any experiences related to contextual aspects of engineering work in these spaces. These findings thus raise questions about the repertoire of experiences and skills engineers have to draw on when needed and how this repertoire, coupled with an undervaluing of contextual aspects of engineering work, may contribute to an underemphasis of contextual considerations in their own work, thus perpetuating the cycle.

# Chapter 6: How Dominant Cultural Values Relate to Practice and Perceptions of Engineering

In this chapter, I explore in detail the experiences of four engineers that range in degree of attention to contextual aspects of engineering work to examine how their experiences in particular engineering contexts related to their perceptions of the field and the aspects of engineering work they foreground in approaching complex problems. Specifically, I address the following question:

> RQ5: How do engineers negotiate their personal values and prioritized aspects of engineering within the engineering contexts in which they engage and how does this relate to their practice and perceptions of engineering?

The previous chapters highlight the aspects of engineering work that participants perceived to be most and least emphasized in the engineering contexts in which they engage and how these align with the aspects of engineering work they personally prioritize. Specifically, my findings suggest that while many participants personally prioritize contextual aspects of engineering work such as accounting for the social or cultural context in which a problem is embedded or its potential future impacts, they perceived these to be among the least emphasized practices in engineering training. Participants varied in the extent to which their responses indicated a high degree of personal emphasis on contextual aspects of engineering work and the degree to which they described dissonance between their personal values and priorities and the foci of the educational and professional engineering contexts in which they participate. Some participants who placed a high degree of personal emphasis on contextual aspects of engineering work described persistent and intense feelings of dissonance and frustration with what they perceived to be a narrow technical emphasis in engineering that largely neglected aspects of engineering work central to their values.

These local and personally-held values may have implications for the types of factors engineers consider in their work. Consistent with findings in Chapter 4 which suggest social and contextual aspects of engineering work are perceived to be among the least emphasized in engineering training, contextual factors were among the least commonly cited considerations in study participants' descriptions of their experiences solving a range of complex engineering problems. Further, study participants described substantially fewer prior experiences related to contextual aspects of engineering as influential in their problem solving approaches, compared to technical factors, internal team dynamics, or immediate constraints such as material resources and project timelines.

The findings outlined in the previous two chapters provided insight into how social and contextual aspects of engineering work were underemphasized across a range of educational and work settings, how individuals differently experienced this emphasis, and how this underemphasis may be perpetuated through engineers' day-to-day experiences and work. In this chapter, I use four brief case studies of individual engineers to provide an integrative understanding of how these findings relate to one another. I explore the interactions among the personal histories and values of these study participants, their experiences in their particular engineering contexts, and their attention to different aspects of engineering work to identify common themes. My case selection and analysis foregrounds participants' degree of attention to contextual aspects of engineering work, building on existing literature (e.g., Cech, 2013; Lattuca et al., 2014; Nieusma & Riley, 2010) and findings from this study that suggest these contextual aspects are frequently underemphasized compared to technical factors. The selected cases were chosen from the 18 individuals who participated in both rounds of data collection, including two participants, Leah and Emerson, who were categorized as embodying high personal prioritization of social/contextual factors in the analysis described in Chapter 4, and two participants, Alek and Nelson, who were categorized as placing a low degree of prioritization of social/contextual factors. In order to better understand the experiences of engineers with varying levels and types of experiences, I selected one undergraduate student (Emerson and Nelson) and one engineering professional (Leah and Alek) in each of these two categories.

Within each case, I describe each individual's academic and professional trajectory, including their role at the time of data collection and motivations for pursuing engineering study or work. These trajectories comprise part of what Holland and Lave (2001) refer to as "history in person" – the personal experiences, cultures, and values individuals bring with them into the contexts in which they engage. In addition to participants' trajectories, I characterize their personal values and priorities related to aspects of engineering work that are also part of their histories in person. These personal histories and values have implications for how individuals experience particular engineering educational and professional environments and the values and practices associated with what it means to do engineering within each. Holland et al. (1998) refer to communities with particular cultural values or resources as "figured worlds," a concept closely related to Holland and Lave's concept of "contentious local practice" – in which individuals negotiate meaning through every interactions with others in a shared context. I seek to characterize the cultural values related to engineering work in the academic and professional contexts in which participants engage. Theses dominant values have implications for engineering practice within these spaces; individuals are incentivized to attend to the most valued or recognized aspects of engineering practice in a given setting and may less readily identify with or be recognized in a setting in which there is substantial dissonance between their values and experiences and the culturally valued forms of engineering practice in that setting. I highlight participants' reflections on their experiences within each context and how the particular aspects of engineering work emphasized in each align with their own priorities. Further, I explore the factors each engineer attends to in solving a problem in a context and the ways these relate to their personal priorities, their past experiences, and dominant values within each space. Finally, because individual experiences are situated within a larger context of engineering education and practice, I describe individuals' reflections on their priorities and experiences within engineering settings more broadly.

**Description of Cases**

As described earlier, I identified four cases to highlight in this findings chapter. Two of these cases, Nelson and Alek, described a low degree of personal emphasis on social/contextual aspects of engineering work in their card sort interviews, as described in my analysis in Chapter Four. Nelson was an undergraduate engineering student heavily involved in a student project team while Alek was a seasoned professional engineer working at a startup consulting company he helped to found. The other two cases, Emerson and Leah described a high degree of personal emphasis on social and contextual aspects of engineering in their interviews described in Chapter 4. Emerson was an undergraduate student who spoke of his experiences in an introduction to engineering class and who was heavily involved in a global health student project team. Leah was an early career professional, who had recently left her position in industry in a tooling firm and was working as a research assistant at a university prior to pursuing a PhD in Design. For reference, Figure 5 depicts the category each participant was placed into in Chapter 4, based on their responses in the card sort interviews. In the sections that follow, I draw on data from participants' first and second phase interviews to provide more insight into their histories, interests, experiences in particular contexts, reflection on these experiences, and personal practice related to engineering.

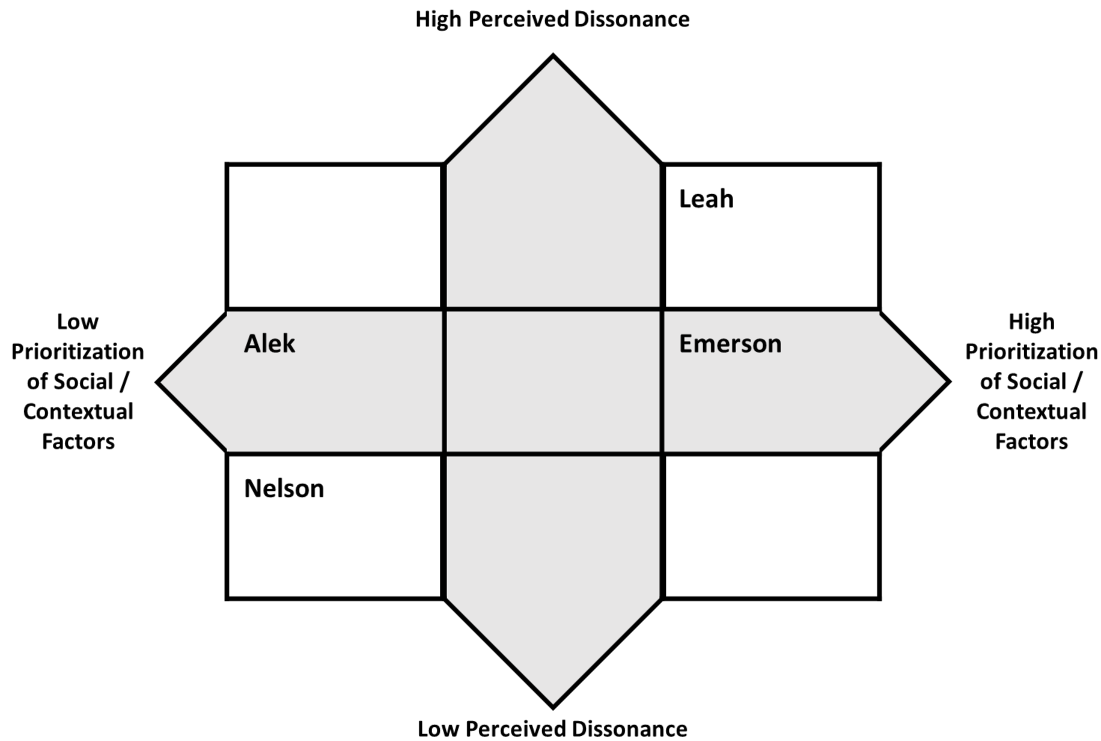


Figure 5: Alek, Emerson, Leah, and Nelson's categorization from Chapter 4 related to their prioritization of social/contextual aspects of engineering and expressed dissonance

*Nelson: Upper-level Undergraduate, Low Prioritization of Social/Contextual Aspects*

At the time of our first interview, Nelson was a 4th year student in electrical engineering, with one year left in his undergraduate studies. Earlier in his studies, he took a semester off to work for a space-related organization and had been an active member in an aerospace student project team since his first year. Nelson explained that he was initially drawn to engineering because of his interest in technology and building, explaining "I have always sort of been interested in sort of the more technical ... Like, I love building things, solving problems. That's just always been kind of a natural path for me." He chose to pursue electrical engineering because of a long-standing interest in electrical circuits and his belief that while electrical engineering allowed him to pursue a career in the aerospace industry, it also provided a broader range of options than an aerospace engineering degree. Overall, Nelson reported enjoying his courses, particularly his more advanced engineering courses. He contrasted what he perceived to be a primarily theoretical focus of his coursework to the more applied "hands-on" focus of his aerospace project team, stating:

> I think course work is definitely more theoretical than practical. The design team is definitely where I have gotten like 80% of all my hands-on actually like think, design, build, test. Like all that process mostly happens in the design team.

While he enjoyed the focus of his team, he explained he also enjoyed both the "more pure theoretical stuff" in his courses. Outside of his engineering coursework and project team work, Nelson did an aerospace internship for a semester and pursued a number of personal building and design projects including circuit boards, 3D printers, and drones.

In our first interview, Nelson described his experiences building a rocket for a student design competition with his aerospace project team in his 3rd year of study. In that year, Nelson served as the chief engineer for the team, responsible for coordinating work across the three sub-teams: avionics, electronics, and propulsion. In his second and fourth years, Nelson served as the avionics sub-team lead. When asked why he felt the project work was important, Nelson cited the primary benefit was useful hands-on experience for team members, preparing them for careers in industry, explaining "the technology, it has been done. A lot of what [team] does in my mind is sort of just the experience for the members on the team. Like a lot of our members go on to work at SpaceX or NASA." While the technology deployed in his team's project was not novel, Nelson pushed to align the technology used in his team to more closely align with that being used in industry.

Nelson’s description of the work and decision-making around his team’s project centered primarily on technical aspects of the design and the interrelationships between components and internal team dynamics. He described the need to consider competition scoring criteria, the merits of different fuel and propellent choices, the machinability and cost of different components, and on-site assembly logistics. These factors largely mirror the engineering practices Nelson described as most emphasized in his project team during our second interview, particularly the emphasis on building a tangible artifact. Notably, Nelson did not describe considering any contextual factors in his team’s project.

The lack of mention of contextual factors was also reflected in our second interview, in which Nelson explained such contextual factors were largely irrelevant to his team’s work, explaining “We’re building a rocket in a university, I’m not sure there’s a ton of cultural context in that. I mean, I don’t know – I think we’re a bunch of college students building a rocket.” Rather, in discussing the main influences on the factors he considered in this project, Nelson cited his experience in previous years’ rocket competitions, machining experience in high school, and experience building things as part of his personal projects.

Nelson’s description of his team’s project highlighted several ways his team negotiated expectations around criteria for decision making. For instance, he described a tension between theoretical optimization and practical, project-specific considerations, evident in his team’s selection of a fuel type for the rocket:

> If [the fuel] builds up in your nozzle, it changes the geometry, it changes the performance. Which sometimes matters when you are burning for, you know, minutes. But our burn is like five seconds. So, it was another one of those things, where all the aerospace guys are like, "Oh, it's an issue." But in practicality, it is not.

Nelson expressed similar frustration in describing how his teammates ignored a concern he raised about the construction of one component of their rocket.  He reflected that, while his concern was based on his experience and intuition, it was likely ignored because he "did not back it up with math," which was outside his own area of expertise. Nelson repeatedly emphasized his reliance on intuition, informed by prior experience, in steering his decision-making in the team, stating:

> A lot of engineering is the technical math, theoretical or whatever, but a lot of it is just intuition. It is seeing a bunch of different situations, make a prediction how it is going to go, see how it is actually going to go, and rewire your brain to think, "Oh okay, well that is how our world works." And the more things you see, the better idea you have of how the world works.

While Nelson was selected to serve in leadership roles on the team for three years and was clearly a valued member of the team, in both interviews, he expressed frustration in instances when his junior teammates did not always listen to and give credence to his experience. While his discussion of his team's decision making suggested differences related to the valuing of arguments made on the basis of data or math versus practical experience, he attributed most of his team member's reluctance to follow his advice as grounded in their reluctance to complicate their work. He explained:

> I think that a lot of the time our suggestions would have resulted in more work and like when, "Oh, this is going to be an issue." The person working on it is like, "It's more work, I think it will be fine." And that's why they do it because they don't want to add complexity.

Reflecting on his rocket team experience in the larger context of his engineering education and work experiences, Nelson described the project as more team-based and more informal compared to other team project experiences in his educational and work experiences. He explained that his project team experiences have been "a great supplement" to his coursework, especially given its applied, hands-on focus. In addition, he described the project as helping him to consider "the overall system," a way of thinking that he did not perceive to be emphasized in his formal education. He explained that, while his courses provided him with foundational engineering knowledge, his project team experiences taught him how to integrate and apply this fundamental knowledge, stating:

> It's like here we're teaching all of this stuff. Presumably you're going to use it for the stuff, but they never say like, here's a problem, here's how to break it down into the fundamental bits. And I think that's where like building stuff, doing projects -- I think that's one of the skills that you've learned [in the projects]: is here's the project, here's how to break it down into the fundamental core things, which you can then apply engineering principles to predict the outcome of the overall system.

Nelson noted several areas where he and his teammates differed in their priorities, and he spoke of the important complementary role his project team experiences played in his overall education. However, as described in Chapter 4, Nelson expressed little dissonance between his personal approach and practice of engineering and the models of engineering practice that he perceived to be most valued in the engineering contexts in which he engaged. In his discussion of the aspects of engineering work emphasized in his coursework and team project, he did not problematize these foci. The activities of the team were closely related to the aspects of engineering work Nelson perceived to be the most important for solving engineering problems in his domain, including tangible building, accounting for relationships between project components, iterating on solutions, and collaborating with teammates. While he spoke of the skills he developed through his project team experiences that were largely absent from his formal education, particularly related to building tangible products and accounting for complex interrelationships, he expressed appreciation for both these team experiences and the theoretical knowledge emphasized in his engineering coursework. Similarly, though he described frustration related to junior team members not always listening to his opinions on how best to resolve technical matters, he was able to have substantial input in the team's decision making as a leader on the team.

*Alek: Advanced Professional, Low Prioritization of Social/Contextual Aspects*

Like Nelson, Alek placed a high degree of emphasis on hands-on aspects of engineering and in his interviews, he did not suggest a high degree of personal emphasis on contextual aspects of engineering design. A mid-career professional, Alek was working in a product development company he co-founded with a longtime colleague. He completed a general engineering bachelor's degree after taking several years off mid-way in his studies. In his final year of undergraduate study, Alek worked as a research assistant in a chemical engineering lab. His research group eventually developed their technology into a start-up, which Alek joined upon graduation. After working at that start-up for seven years, Alek was recruited to work for another local start-up that also had its roots in university research. After several years in the role, Alek teamed up with a business partner—the two were both undergraduate research assistants in the same lab—to found a product development company. The company primarily worked with academic start-ups in medical and life-science fields to help them with product development and navigating regulatory processes. In Alek's nine years in the company, it grew into an organization of 10 employees. In general, Alek described being quite satisfied with his current role, explaining "I think that was what I wanted to be doing. The best part of college was kind of in that very varied cross-disciplinary type of environments where you had to bring lots of different skills to projects or into companies to do stuff."

In our first interview, Alek described a project with his company helping an academic research group working to commercialize a medical device to treat a common but non-lethal condition. He had previously worked with the company to build a version of their device for human trials and the success of that device resulted in additional funding for product development and further trials, which he discussed in our interview. Alek served as project manager for the work and was also responsible for navigating regulatory aspects of the project. Time-pressure was a major factor in the project, which involved multiple phases, including six months of initial product development and iteration, followed by what Alek described as “a lot of troubleshooting, and figuring out now that we had kind of an integrated system, what parts weren't working as expected, or were, and what tweaks did we need to make.” Alek also explained that hearing inquiries from people who suffered from the condition the device was addressing strengthened his motivation to work on the project.

Alek described a number of considerations when approaching this project, including negotiating the scope of the project, who was responsible for product testing, and the timeline with his client. In addition, he discussed factors related to the technical design of the device, such as device component selection and equipment sources, software customization, and device fabrication logistics, and well as those relating to the user experience, including the durability of the device, the user interface for trials, and device portability. Alek explained that his previous experience working with the same client was quite similar to the work in which he was engaging during the time of our interview: “basically we made very similar devices.” Thus, he described “building on top of previous experience,” including using similar components to those used in previous designs whenever possible and using familiar design tools. He explained he had learned to use “off-the-shelf stuff” for early designs as much as possible because “you don’t do the customization until after you’ve gotten something that’s working.” In the project he discussed, his main priority was the technology novel to the device, though he said that, for commercial use, he would place a higher priority on the user interface and packaging.

Comparing the project he described to his prior engineering work, Alek named a number of similarities. In particular, he explained that, while the technological aspects of any engineering design are “pretty clear if it’s working or not working,” the challenges of a company working with start-up clients came in the form of communicating with and managing relationships with clients. He noted that these aspects of the work tend to be more complicated:

> From a big-picture standpoint, it's not the underlying engineering or the physics that creates a lot of the work or stuff. It's more of the figuring out what people want, and the communication.

Consequently, Alek described his efforts to ensure his employees have a broad repertoire of technical knowledge and experience. He noted paying particular attention to areas where previous challenges arose, stating:

> And so a lot of it is just building up a knowledge base of things that we have experience with. And so yeah. So looking at projects from that standpoint, I'm like, "But here's where we started... We didn't accomplish what we needed to accomplish, but here's kind of where we struggled. What tools could we bring or what other solutions could we evaluate for the next time?" Because there's a lot of, sort of, repeat work within specific projects that it'd be nice if it we had something we were comfortable with, that we can just use.

Alek identified a number of skills he perceived to be key in solving complex engineering problems, first among which was communication. In addition, he described the importance of research skills to identify a problem and potential solutions, accounting for both technical and non-technical factors, which he described as “like the speed and some of the portability side of things.” He also emphasized the importance of being able to identify the biggest technical challenges in a project and how various aspects of a problem related to one-another. While Alek placed a high degree of emphasis on interpersonal relationships and communication skills, both within his team and with clients, he focused on the contexts most proximal to the problem. He explained in his second interview that cultural aspects of a problem in particular, “tend to fall outside of what we would do on a project.”

Overall, the factors Alek considered in the project he described and his experiences in his company more broadly were well-aligned with the aspects of engineering work that he personally felt to be most important. Alek had achieved success in several companies in his domain and was eventually in the position to co-found his own company, giving him a great deal of control over the nature of the work within the organization. This alignment between the aspects of engineering work he personally prioritized and those emphasized in his work context was reflected in his second interview, in which he explained the emphases “tend to overlap.” However, the dominant emphases in his current workplace stand in sharp contrast to his experience in his undergraduate degree program. Like Nelson, Alek described his undergraduate coursework as more theoretically oriented, but Alek perceived this emphasis to be more problematic than Nelson. Similarly, however, Alek described extracurricular opportunities that help students develop these skills “like the solar car and the submarine and those kinds of projects.” Alek expressed a greater degree of frustration about the curricular focus of engineering than did Nelson and lamented that practical building skills were not “part of the core.” In fact, Alek explained, the narrow theoretical focus, and neglect of hands-on building experiences were among the reasons he founded his company:

> And one of the reasons we formed the company was we came out of... college, we had engineering degrees but we didn't know how to do engineering. And so we hired consultants to try to tell us how to do the worker we were supposed to do. And they would tell us what we were supposed to accomplish, but not necessarily how to accomplish it. And so I think one of the reasons we founded this company was we wanted to actually explain to people what they were supposed to accomplish and then help them accomplish it.

In his role at the time of the interview, Alek felt he was able to address an unmet need. Alek also participated in a mentoring program for students from his alma mater in “effort to bring some more understanding into the groups there” of aspects of engineering work he felt were largely neglected in his own education. In addition to his desire to see more tangible building skills addressed in engineering education, he also described collaboration and communication – skills he considered critical in his current role – as generally underemphasized in engineering education.

*Emerson: Early-level Undergraduate, High Prioritization of Social/Contextual Aspects*

In contrast to Nelson and Alek, Emerson expressed a high degree of personal prioritization of cultural and contextual aspects of engineering work. At the time of our interview, Emerson was completing his sophomore year of college as a biomedical engineer. He explained that he went to a well-resourced high school and felt like he had a good foundation for his engineering coursework. Though college proved to be an adjustment, Emerson was feeling more confident, but described the environment as very competitive:

> The atmosphere around college is very—especially here—is very, very competitive and you feel everybody just wants to kind of talk about how well they're doing. It takes you a minute to realize that other people are struggling as much as you are.

He explained that he pursued engineering because, “like most engineering kids,” he was always good at math and science. While he considered pursuing architecture because of his interest in art, his mother encouraged him and his brother to pursue engineering. Emerson described the primary draw of engineering, and biomedical engineering specifically, was the potential to have “a direct benefit,” stating:

> I was like, "I want to do something that really impacts people." And I've always really wanted to help people on a very, kind of real concrete basis. And I'm like, "I don't want to just be an engineer who designs some little part that goes into something, that goes in something that eventually does something. I want to be able to see, kind of the impact of what I'm doing right away.” And that's what really motivates me as a person to be able to kind of see my work, not just to get money, but to do something that I think is valuable to the world. So I was like, "Biomedical Engineering, that's for me."

When asked if his engineering coursework was what he hoped it would be, he answered “not yet,” explaining he enjoyed his project-based introduction to engineering course and is looking forward to more applied labs. In addition to his BME major, Emerson was pursuing an international minor that involved a summer study abroad experience. He described his interest in the minor stemming from a desire to “change the world” and have impact beyond the “little sphere of where we are in the US.” Outside of his coursework, Emerson was a member of a medically-oriented project team that foregrounds social good. He described being eager to get more involved and advance the work of the team, asking himself “How can I put more time and energy into this project team? What else am I doing that maybe isn't as fulfilling to me that I can cut back on?”

In our first interview, Emerson described his experiences working on a team project in his introduction to engineering course in his first year. The course project involved building a video game for a visually-impaired client. Though the course was not directly related to Emerson’s interest in biomedical engineering, he explained why he selected the course:

> I was particularly drawn to kind of his project, because it was very human in a way. I think, I hear about the people who are building blimps or underwater vehicles. And I'm like, "That's cool. But why? What's the effect of that?" Again, like going back to I always like to see the immediate effect of what I'm doing. How is this helping someone live a better life?

The course emphasized working closely with the client and soliciting their input, something Emerson enjoyed. He described the project’s importance as related to the larger social implications and its alignment with his own passions, stating:

> I think in general it's important to, I guess, increase awareness of accessibility in things like that. I mean, because I've been involved in a little bit of like social justice type work at the university. I think I've become more aware of that. And kind of sometimes the, I guess, limits to ... Like accessibility for people with different disabilities and things like that

Emerson described a number of considerations in his team’s approach to the project, including coordinating the work between group members and the course grading criteria, which required them to include a scoring system, visual effects, and appeal to the client. He recounted that his team was recognized for their efforts to engage with the client, stating:

> That was actually something that our professor kind of applauded our group on a lot, was our ability to kind of work with her, and how closely we were trying to kind of make sure that our design process was reflective of what we had. The feedback that we had gotten from her, with initially meeting her and kind of hearing her interests, and things like that.

Other factors Emerson described included the project timeline, the skills and knowledge of team members, a feeling of competition with other groups, and feelings of pressure to stick to the project plan his group initially outlined. When prompted for additional factors, Emerson mentioned budget and potential future development of the game but that largely the course content limited the external factors he and his team considered:

> And I think because it was a class project, we weren't, I guess, focused as much on like more external factors like a lot of the things that you named. Because I think a lot of it is, you tend to be like, "Okay, I'm doing this project to get this grade for this class." And I try to not think that way. And I think overall the class did a good job of making us not think that way, because it was a practice in socially engaged design, because we were working with a specific client.

He connected his concern for the client's experience to a similar client-oriented emphasis of his extracurricular medical design project team and his previous self-directed study in high school in which he learned about the consequences of designs not accounting for the needs of users. Reflecting on the project, Emerson suggested that absent the course grading criteria and semester timeline, he might have been more willing to take risks.

Reflecting on his broader engineering experiences, Emerson explained that his course experiences mirrored his extracurricular project team's emphasis on balancing stakeholder needs with what is feasible and that communication between group members was equally important in both contexts. Emerson also described a personal emphasis on "brainstorming," something he viewed as emphasized "a lot in group work and group projects in school nowadays." However, he felt that he did place more emphasis on needs assessment than other engineers, stating "I like to kind of really know the problem very well before I jump into a solution." In addition, he perceived his emphasis on social and contextual aspects of engineering as something that distinguishes him from many engineers, explaining:

> I really like to think of the social implication aspect of what I'm designing in my engineering. And I think that that's—dare I say—a strength of mine in engineering, or at least something that I think sets me apart a little bit. That I try to play to, I guess I should say in my engineering, is the fact that I am someone who enjoys social sciences. So I can kind of utilize that and be able to have those strong communication skills, and think about problems in a way that's not just technical.

He related this focus back to a high school experience in which he had researched kinetic charging devices for use by people in developing economies, only to find that many of these solutions were unsuccessful or "marketed at rich, white people in the US." For Emerson, this experience influenced his desire to "be an engineer who has a social impact," asking "What's really the best way I can do that without falling into these pitfalls?" He explained that while some experts in his field were able to think about problems on a "complex level, thinking of the social implications" he sometimes felt frustrated that his peers lacked this focus. However, Emerson explained that he hoped this would change in the future, stating, "right now, we're all just like, "We like to build things. So let's just be engineers who build things. But I realize that there's more to that. And hopefully my peers will come around to that, too."

Emerson's consistent motivation to create social good through engineering work was reflected in the projects he selected and extracurricular experiences in which he engaged. As described in in Chapter 4, while Emerson was able to seek out experiences that emphasized social and contextual aspects of engineering work, he did not perceive these to be common emphases in most engineering courses. Further, he explained that even in instances when social responsibility in engineering was discussed, it was often in broad terms and rarely involved explicit instruction on how to account for social and contextual considerations in engineering problem solving:

> I think sometimes whenever we do talk about social responsibility it's in a very broad context of "make sure you're being socially responsible." But then we don't really go in to how to do that. I think from the classes I've taken and just in general, any experience I've had with thinking about here, it's very much about here's what not to do. […] But we didn't even quite get to the point where it was like "here's what to do."

While he expressed a desire for more attention to these social and technical aspects of engineering work in his courses, he also hoped for more tangible building experiences, explaining that the opportunity to build something made his introductory engineering course one of his favorites. He spoke of the importance of considering the interplay between technical and social aspects of a project, concluding “you can't just think of the technical things of technically this is more efficient, technically this works better. You also have to think, how does it interact with the society around it because otherwise it's not going to be used or it's not going to be used properly.” Despite his perceptions that his education to date underemphasized several aspects of engineering work important to him, Emerson did expressed feeling particularly constrained or alienated by this dissonance, generally framing his approach as a strength and expressing hope that he might find his more advanced classes to be a better fit with his interests.

*Leah: Early-career Professional, High Prioritization of Social/Contextual Aspects*

Leah was an early-career engineer with a bachelor’s degree in mechanical engineering. After graduating, she worked for a little over a year at a hand tool company before deciding to leave to seek other employment, and eventually a PhD, at her undergraduate institution. Like Emerson, Leah’s interest in engineering stemmed from a long-standing desire to “change the world,” explaining:

> I wanted to do something good in the world and I thought engineering was the place you learn how to do that. So that drew me to it. I don't think that's what keeps me here, but it certainly is what drew me to it.

Consistent with what she shared in our second interview (see Chapter 4), in our initial interview Leah expressed a great deal of frustration about the emphasis of both her undergraduate coursework and her professional work experiences, explaining that the emphases of both were not well-aligned with her desire to have a positive social impact with her work. She elaborated on her undergraduate training, stating:

> I thought we were going to get to meet people and learn about the world's problems and do good things. Instead you're just sitting in a class learning a bunch of equations, which is fine. Academically I can do that. It's not like it was too hard or anything. It was just not that interesting.

Because of this frustration, Leah sought out extracurricular involvement in a socially-oriented design organization which emphasized interdisciplinary collaboration and ethical design practices that foregrounded social and cultural considerations of design work. After leaving her job at the tool company due to frustrations about the organization’s focus and culture (described in further detail below), Leah pursued design research work at her university and, at the time of our interview, had been accepted into a design-focused PhD program. She described her intended pursuit of a PhD as “the first step of academically combining my design work with my engineering work.”

In our first interview, she described that she worked on in her former role in the tooling company, focused on launching a new tool line manufactured domestically. Leah’s role on the project was to coordinate efforts to manufacture the tools domestically, identifying manufacturing methods and suppliers. She described initial interest in the project, explaining that she saw the importance of being able to manufacture quality products domestically and affordably while maintaining high quality standards. In addition, she saw the project as potential opportunity to benefit customers by building quality tools and considering a broader market for the product – a direction her company was not interested in pursuing. She explained:

> Basically anything you're designing could be something that I would be interested in, but for me it's got to understand and appreciate the larger context of where it's going to be used and where it's impacting people's lives […] But they weren't really taking on the really hard questions of why is it that our stereotypical user is a middle aged white man who's relatively wealthy ... not wealthy, but pretty well off and able to purchase all these tools. Why is that our stereotype? Why do we have to continue advertising to those people? Why are we only catering to them? Why are we only considering them in our design decisions? They weren't really interested in kind of pushing the boundaries in the way that I had thought they were going to be.

In approaching this project, Leah spoke extensively about weighing various manufacturing methods, suppliers, and material resources. She also described a consideration of a wide range of other factors such as available technology, the project timelines, interpersonal relationships with suppliers, stakeholder needs, the financial and environmental implications of shipping distances for different parts, and the economic implications of manufacturing domestically. Leah also demonstrated mindfulness about the ways these various factors were interconnected and tried to understand the implications of individual decisions on other aspects of the problem. However, as she explained, this was not a skill nor priority shared by her collaborators:

> I think I would have done things a bit differently just in the fact that my team, especially two team members that I worked with were so could really only see the thing right in front of them and I think one of the things that I was good at and that they were not was okay, what about the next 10 things that are going to come down the road because of that decision?

Leah described a number of instances in which her input was ignored or constrained to a narrowly-defined topic. She explained that she quickly learned it was not "her place" to make design recommendations related to the project and that her supervisors were not willing to listen for several months when she raised concerns related to the feasibility of their intended product release date, pushing it back only at the last minute. In our second interview, Leah described a number of ways the aspects of engineering she perceived to be most valued within her workplace were in conflict with her personal priorities. For example, she cited the company's high regard of fundamental engineering research, which she described as disproportionately valued even if the "information wasn't super relevant or helpful or practical." Additionally, she took issue with her supervisor's view on collaboration, explaining cultural assimilation based on shared interests and humor was seen as key, stating "It was really important to this company that the people had similar cultures because I think they thought if you fit in culturally, you're going to work productively. But it turns out those things aren't really correlated all the time." Despite these frustrations, Leah detailed several ways in which she was able to successfully push on company priorities, describing how she was able to encourage sharing ideas and expertise within her company, explaining:

> When I started at the company, this was not valued at all because it was all about, you can learn anything on your computers sitting behind a desk, reading a book. But over the course of the year that I was there, 14 months I was there, this became more valued because I demonstrated over time. It's really important to learn from experts in the field […] this was not important, but sort of became more important over time.

Ultimately, however, Leah felt that both the aspects of engineering work and cultural values emphasized in her workplace were too far out of line with her personal priorities, explaining these disconnects as her reason for leaving her position despite success at her job.

Comparing her work project experience to other engineering experiences, Leah described the key role of trust and relationship building across projects. She also spoke of her personal prioritization of a "big picture" perspective across projects, a skill she did not perceive to be commonly emphasized in engineering education, stating:

> I think I'm particularly good at considering how all of the pieces pull together and this bigger picture view. I think I'm quite good at organizing information in a way that communicates to myself and other people why all these things are connected, I would say. I think it's really difficult for me to only consider one piece of it, which is why I'm a terrible engineer when it comes to sitting down and engineering but in the traditional sense, in the stereotypical sense of what an engineer does. But I think I'm a really good engineer when it comes to how is this going to impact people? How does this impact each other? Who has to be a part of

> this? Those bigger picture concepts, which are not, I think, valued as ... understood in engineering education. I think that's what I'm particularly good at and that's what I trend towards.

She expressed frustration about a lack of alignment between her engineering education experiences and the skills she perceives to be necessary in engineering and design work, stating "it just bothers me how little my education aligns with my actual design and engineering experience." Related to Leah's "big picture" emphasis, she repeatedly described her prioritization of the social and contextual aspects of engineering as central to her approach and also largely missing from her educational and professional experiences. She posited:

> Maybe that's the reason why these things are so important to me because I see them as missing, and I also see them as core values of mine. […] I think that these are things that I see as missing from all of those experiences, and I also see them as solutions to the problems I had in those experiences.

Though Leah continued to encounter dissonance between her personal priorities and the dominant values of her engineering education and professional experiences, she remained committed to practicing engineering in a way consistent with her personal priorities, seeking out an environment in her design-oriented PhD program that she hoped would prove to be a better fit.

**Summary of Findings**

This chapter provided an in-depth look into the experiences of four engineers and the ways they made sense of their prior experiences and personal values within the context of a particular engineering project and within engineering more broadly. Two of the participants, Nelson and Alek, most highly prioritized technical aspects of engineering work and spoke little of contextual considerations both in their individual projects and in reflecting on the aspects of engineering work they emphasize more generally. While both Nelson and Alek described their engineering coursework to have a primarily theoretical focus, only Alek expressed substantial frustration with this focus, having found upon graduating that his education did not adequately prepare him for the engineering work he was interested in pursuing. However, Alek was able to build relevant experience through membership in a research lab and on the job experience in a related start-up upon graduation and eventually found himself in a position to co-found his own company and advocate for a focus on the aspects of engineering work most important to him. At the time of our interview, both Nelson and Alek found themselves in engineering contexts in which aligned with their personal values and enabled them able to attend to aspects of engineering work that mirrored those they personally prioritized. Both Nelson and Alek held leadership positions within these contexts that gave them substantial say in the practice of engineering within those settings.

In contrast to Nelson and Alek, both Emerson and Leah placed a high degree of personal emphasis on contextual aspects of engineering work, though both also described proficiency at and passion for more technical aspects of engineering design as well. Emerson and Leah were both driven to pursue engineering out of a desire to have positive social impact with their work. Neither Emerson nor Leah perceived contextual aspects of engineering work, core to their personal engineering practice and values, as well-represented in their engineering coursework. However, in contrast to Leah who reflected on her persistent frustration about the lack of contextual emphasis throughout the course of her degree program, Emerson expressed hope that a greater emphasis on social and contextual aspects of engineering would be present in her later courses. Emerson and Leah's focus on social and contextual aspects of engineering work was reflected in how they approached the projects they described in our first interview—both discussed at length the potential beneficiaries of their work. In Emerson's case, he described the projects' emphasis on at least an individual stakeholder to be aligned with his priorities, though noted the course-based nature of the project restricted his and his team's consideration of broader contextual factors. For Leah, her focus on social and contextual aspects of the engineering problem was actively discouraged. In light of the tension between Leah's personal emphasis in engineering and those of her company, as well as broader cultural issues within the company, Leah elected to quit her job despite her company's general satisfaction with her performance.

**Key Insights**

Several key insights derive from these four cases. First, the positivist ideology that underlies much of engineering work (Cech, 2013; Faulkner, 2007; Riley, 2008; Williams, 2002) and champions technical knowledge above all else is evident both in the accounts of Leah and Emerson, who describe the lack of focus on cultural, social, and contextual factors in their education and work, but also in Nelson's story. In describing his teammates' hesitations to listen to his advice grounded in years of experience, Nelson posited that this was because he "did not back it up with math," which he felt would have carried more weight when arguing his case with his peers.

Second, these cases also demonstrate how a narrow technological focus is perpetuated in engineering, beginning with participants' individual engineering practice. Nelson and Alek appeared to largely accept the primacy of technical considerations, though they varied in their personal perceptions of the merits of theoretical versus hands-on forms of technical engineering knowledge and work. Nelson described social and contextual considerations as not relevant to his project team's work, explaining they were merely "a bunch of college students building a rocket" without consideration of application. He supported this inattention to contextual considerations despite acknowledging some of his teammates may eventually apply their skills to missile development, explaining his team explicitly did not let such considerations shape their work on the team. Similarly, despite working in a medical context, Alek described limited consideration of social or contextual factors in his practice. While he spoke extensively of his relationship with his company's client developing device technology, he primarily discussed the physical design of the device and usability when considering the device's prospective users. Though there are a number of social and cultural considerations that might shape users' engagement and use of a particular medical device, he described social and contextual considerations as things that "tend to fall outside" of what his team would consider in a given project. In Leah's case, while she personally advocated for a broad consideration of a wide range of social and contextual factors in her professional work, she explained attention to these factors were discouraged by her company, whose leaders instead preferred to leave unexamined their assumptions about how and by whom their devices may be used. To a lesser extent, Emerson explained that the format and timeline of his introduction to engineering course restricted both the necessity and ability for his team to attend to broader contextual factors in their work.

Third, while different engineering contexts emphasize various aspects of engineering work, an emphasis on social and contextual factors was not evident in the core of engineering training or professional practice described by these four participants. All four participants described the need to seek out activities beyond their coursework in order to fully engage in the aspects of engineering work they personally prioritized. Despite very different personal priorities, all participants noted that extracurricular activities provided additional learning opportunities that went beyond the primarily theoretical, technical focus of their engineering coursework. This finding raises questions about the extent to which engineers must rely on self-initiated activities, which may require a tradeoff between their attention to coursework and other responsibilities that not all students are able to make, in order to develop skills and engage in engineering environments that most closely align with their goals and values. This necessity may be particularly pronounced for engineers who value social and contextual aspects of engineering work that are outside the normative focus of the field. For an introduction to engineering course that was human-centered, Emerson had to go outside his own area of engineering while Leah described seeking opportunities beyond engineering disciplinary boundaries altogether, engaging in both a multidisciplinary design organization and eventually a multidisciplinary design doctoral program in order to engage with aspects of engineering important to her.

While all four participants spoke of the importance of seeking out additional experiences for developing important engineering skills, the nature and consequences of any disconnect related to values about engineering work in various engineering settings looked different for each participant, as did the degree of dissonance each described. Nelson, whose own priorities aligned well with the dominant technical values of his engineering contexts, reported little dissonance related to the nature of engineering work, instead only expressing moderate frustration related to interpersonal dynamics within his project team. Alek, who like Nelson, described his current work to be well-aligned with his personal values, described dissonance related to the focus of his undergraduate studies in that they prioritized theoretical aspects of engineering over hands-on aspects. He primarily expressed this dissonance not as a threat to his or others' perception of him as an engineer or his place in the field, but rather that his undergraduate studies did not adequately develop relevant professional skills. It is notable that, for Alek and Nelson, who valued the applied and technical aspects of engineering that are commonly recognized as being the core of engineering work (Cech, 2013, Faulkner, 2007), eventually obtained positions of authority and status in engineering contexts with dominant values very similar to their personal priorities.

Leah's case is a stark contrast to Alek and Nelson's. She described disillusionment and consistent frustration with engineering work in both her educational and workplace settings, where the underemphasis on social and contextual aspects stood in sharp contrast to her original interest in engineering because she saw it as an opportunity to do social good. As a result, Leah described feeling her contributions and thinking related to the contextual aspects of engineering work were not valued or recognized, that she could not represent her full self in those spaces. Ultimately, this dissonance led to her decision to leave her job and seek doctoral study in which she hoped to better integrate her passions and work. Like Leah, Emerson was motivated to pursue engineering to effect positive change and perceived an underemphasis on social and contextual factors in his engineering training to date that did not yet help him toward this goal. Both Emerson and Leah expressed dissonance related to a desire for more emphasis on contextual factors in their engineering training. Emerson, who was early in his undergraduate studies, expressed hope that such an emphasis would be more evident in his future coursework and that his peers would similarly come to see the value of social and contextual engineering skills. While, for both Leah and Emerson, engineering's underemphasis on social and contextual aspects of engineering was a source of dissonance, they hoped for a greater emphasis on these *in addition to* an in-depth technical focus; both expressed a passion for the technical challenges of engineering work, they just also hoped these would be addressed alongside a consideration of the broader context.

## Chapter 7: Discussion and Implications

Faced with the challenges of a complex global world, it is critical that engineers be able to attend to a broad range of factors when addressing such challenges. In particular, there is increasing recognition about that, in addition to the field's focus on technological facets of problems, engineers must be able to account for social and contextual considerations that affect and are affected by engineering solutions (ABET, 2017; Amadei & Wallace, 2009; Catalano & Baillie, 2006; Lucena, et al. 2010; Moskal, et al., 2008; UNESCO, 2010). A failure to account for these social and contextual aspects of engineering problems can result in solutions that are not useful or even harmful to the people and societies they are intended to benefit (Nieusma & Riley, 2010; Tenner, 1997). Further, a narrow technological focus may alienate students drawn to engineering out of a desire to have a positive impact on people and communities with their work, a group that disproportionately includes women and minority students (Chesler & Chesler, 2002; Colvin, et al., 2012; Fraser et al., 2013; Litchfield & Javernick-Will, 2015; Smith, et al., 2014; Swan, et al., 2014).

However, calls for broadening engineering work to include an emphasis on social and contextual elements runs counter to the dominant ideology of engineering, which is grounded in positivism and a belief that engineering work can and should be separate from any social or non-technical considerations (Carter, et al., 2019; Cech, 2013; Harding, 2015; Riley, 2008). This tension raises questions of if and how, in light of these widely held beliefs about the nature of engineering work, the field might adapt to better account for social and contextual aspects of engineering work. How and what might engineering students and professionals learn about core aspects of engineering practice and what are the implications of these cultural values on their own engineering work and their understanding of the field of engineering and their place within it?

This study was motivated by my desire to better understand this tension between technical and contextual considerations in the engineering field and implications for how engineering work is defined, practiced, and understood in relation to one's own role as an engineer. My overarching goal was to understand why an underemphasis on social and contextual aspects of engineering work persists, despite top-down calls for change and how this underemphasis is experienced by engineering students and practitioners, including any potential dissonance they perceive as a result of misalignment between their priorities and dominant emphases of the field and the implications of this dissonance for their fit within engineering. While prior research describes field-level trends of underemphasis on social and contextual awareness within engineering work and education (e.g. Lattuca, et al, 2014; NAE, 2004; Riley, 2008), I sought to understand how this underemphasis is perpetuated through practice within local engineering contexts as well as the consequences of continued underemphasis for engineers' understandings of the nature of engineering work and their role within the field. Local contexts, such as one's academic department or workplace, are important to examine because they serve as the sites in which individuals learn about core values of engineering work and develop as engineers. In service towards my larger goals, this study addressed a series of specific research questions:

> RQ1: What engineering practices do participants perceive to be most and least emphasized in the engineering contexts in which they engage?
>
> RQ2: How do these emphasized practices align with those practices and values participants personally consider to be most important?

RQ3: What types of factors do engineers most commonly attend to in addressing complex engineering problems?

RQ4: What educational, professional, and personal experiences do engineers cite as influential in their consideration of various factors when solving engineering problems?

RQ5: How do engineers negotiate their personal values and prioritized aspects of engineering within the engineering contexts in which they engage and how does this relate to their practice and perceptions of engineering?

To address these questions, I drew on data from interviews with 46 engineering students and practitioners about an experience solving complex engineering problems and their experiences in engineering more broadly. In addition, I conducted follow-up interviews with a subset of 18 of these participants, guiding them through a card sort exercise as a means to facilitate their reflection on the aspects of engineering work emphasized in the educational and professional contexts in which they engaged and how these aspects aligned with their own ideas about important aspects of engineering work.

In this chapter, I provide a conceptual overview of the aspects of engineering work emphasized in various engineering education and work contexts, explore how an underemphasis on social and contextual aspects of engineering may be perpetuated through practice, describe how engineers differently experienced and responded to the emphases of engineering work in a range of academic and professional settings, and discuss the potential implications of my findings. I leverage existing literature in engineering education, as well as social practice theory frameworks (Holland et al., 1998; Holland & Lave, 2001; 2009) to discuss and integrate findings from the multiple analyses of this study.

### Characterizing Dominant Cultural Values within Local Engineering Contexts

Existing literature highlights a persistent positivist ideology within engineering regarding primacy of technological knowledge and the belief that this knowledge alone, unaffected by social or contextual considerations, can and should drive engineering decision making (Carter et al., 2019; Cech, 2013; Faulkner, 2007; Riley, 2008; Williams, 2002). Research suggests that an underemphasis on social and contextual aspects of engineering work persists, despite high-level advocacy for change. For example, in 1996 the Accreditation Board for Engineering and Technology adopted a new set of expanded student learning outcomes as part of a new set of standards that included ethical and contextual awareness. However, despite this national push, a study of the impact of these criteria suggested a majority of faculty members reported little change in their courses on the emphasis they placed on engineering in global and social contexts, knowledge of contemporary issues, and professional ethics (Lattuca, Terenzini, & Volkwein, 2006). In effort to understand why and how this underemphasis persists, despite growing recognition about the importance of attending to a broad range of engineering factors, my work explored how individual engineers encountered and experienced emphasized and underemphasized aspects of engineering across a range of local contexts.

Local contexts, such as engineering courses, co-curricular project team experiences, and professional workplaces, are important to understand because they serve as the primary locations in which engineers learn about and enact engineering work. These local engineering contexts, while embedded in the larger cultural context of engineering, may vary in the values emphasized and forms of engineering practice, such as the extent to which engineering work in those spaces includes the consideration of non-technical factors. Holland et al. (1998) refer to local realms of interpretation as “figured worlds,” in which meanings are ascribed to certain actions, and particular acts or outcomes are held in higher regard than others. Engineers’ practice within these figured worlds are both shaped by the dominant values within them and, in turn perpetually reconstitute shared meanings and images of engineering work within them through their own practice of engineering. Thus, within engineering, identifying the forms of practice individuals perceive to be most or least valued within a given engineering setting can provide insight into how and where narrow technical definitions of engineering work may be reproduced—or challenged. In one part component of my data collection strategy, I asked participants to identify the engineering practices they perceived to be most and least valued in the engineering contexts in which they engaged. This exercise revealed some of the cultural practices that constitute engineering work in a range of educational contexts and a subset of engineering workplaces.

Across both undergraduate and graduate education contexts, the forms of engineering practice most commonly identified as highly emphasized included technical communication, analyzing a problem and defining the constraints, interpreting data, and collaborating with others to achieve a common goal. These emphases mirror 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 (Lattuca et al., 2014). In my study, participants further recalled a high emphasis testing and evaluating potential solutions, building tangible artifacts, and drawing on science and engineering principles to predict outcomes during their undergraduate education. In contrast, in graduate education contexts, more than a third of my participants reported a high emphasis on several research-related practices, including developing plans and procedures for experiments, coming up with innovative ideas, and conducting research on fundamental principles. This emphasis on research practices within graduate engineering contexts is unsurprising given the importance of these skills for graduate work in engineering (Golde & Walker, 2006; Rogers & Goktas, 2010).

While collaboration was widely perceived to be valued in both graduate and undergraduate educational settings, demonstrating social awareness and empathy was not; a large proportion of undergraduate and graduate students named these among the least valued or emphasized practices in their educational experiences. In graduate settings, participants also commonly named another social skill, related to demonstrating leadership within teams, as not widely valued or emphasized. In addition, contextual and breadth-related practices, including accounting for the social and cultural context in which a program is embedded and incorporating ideas and approaches from other fields of study, were among the least valued in both undergraduate and graduate education contexts. Within graduate contexts, 30 percent or more of respondents also named context-related practices such as accounting for potential future impacts and accounting for the natural environment, as among the least valued or emphasized. In the main, the common perception that many contextual practices are not emphasized in engineering education contexts further echoes previous research findings, in which faculty and instructors reported that contextual aspects of engineering work were less emphasized in their engineering courses compared to many other facets of engineering work (Lattuca et al., 2014).

In professional engineering contexts, multiple participants noted the high value placed on teamwork-related practices, including collaborating with others, demonstrating leadership within teams, communicating effectively about work with people from other academic or professional backgrounds, and managing work across all stages. Several participants named coming up with innovative ideas and building tangible artifacts as highly valued practices. The value of accounting for the social or cultural context of an engineering problem differed according to the workplace setting; it was among the most commonly named most *and* least valued practices. This dichotomy likely reflects the range of workplaces described by participants in the study. As

Holland and Lave (2001) point out, while local practice is informed by the larger cultural context, there is variation in how these larger values are negotiated at local levels. In this instance, several participants described work in human-oriented workplaces in healthcare and education, in which a social and cultural focus may be more valued, compared to engineering work in automotive or tooling industries that may be closer aligned with hands-on, technical aspects of engineering work. In addition, over half of participants in professional settings named accounting for the natural environment as among the least valued practices in their workplace. While some scholars (e.g., Stevens et al. 2005; 2008; 2014) argue that an underemphasis on nontechnical aspects of engineering work in engineering education stems primarily from a lack of exposure to professional engineering work in which a broader set of nontechnical skills are needed, findings from the present study suggest that professional engineering contexts do not necessarily place a substantially different degree of emphasis on contextual dimensions on engineering contexts than did engineering education contexts.

While overall trends suggest a persistent underemphasis on social and contextual aspects of engineering work across both educational and professional settings, several participants described particular courses, co-curricular activities, or research teams that placed substantial emphasis on these aspects. However, these participants consistently described such an emphasis in these local settings as an exception to their experiences in engineering as a whole and/or as emphasizing forms of practice outside the technical core of engineering work. Several graduate student participants who described working on research teams that more highly emphasized social and contextual considerations contrasted the focus of the work in these teams to the majority of their experiences in engineering and to the emphasis of the field more broadly. One participant, Paris, expressed frustration about an emphasis on contextual aspects in her introduction to engineering course. While the course devoted only one class session to contextual considerations, she explained that an attention to contextual factors further constrained students' solutions and that she wanted to first ensure students learned technical knowledge, which she referred to as "the facts," before considering potential implications of engineering work.

Overall, these findings echo existing literature that points to a widespread and persistent underemphasis on social and contextual aspects of engineering practice. Examining individuals' perceptions of what is emphasized in the local contexts in which they engage, however, provides insight into some nuanced differences between different engineering settings. For instance, my findings highlight instances in which engineers do perceive contextual skills and knowledge to be emphasized within a particular context. Yet, the fact that engineers engaging in such local contexts characterize them as an exception compared to the majority of their engineering experiences or characterize the social and contextual practices emphasized as falling outside the core of engineering practice, highlights the dominance of positivist ideologies that equate engineering work with strictly technical knowledge. Engineers' understandings about the most valued or recognized practices in the field appear to remain unchanged from experience in a single contrasting local context, even in instances in which they personally value a broader range of engineering practices. Experiences that occur *outside* typical or core engineering contexts – the classrooms and workplaces in which nearly all engineers engage – are insufficient for shifting popular conceptions about "what counts" as engineering because these *other* experiences perpetuate social and contextual aspects of engineering work as peripheral and optional. These findings, related to the continuing underemphasis on contextual considerations, raise questions, which I address in part in the following sections, about how narrow understandings of engineering work are reproduced and change may occur.

**How Dominant Cultural Values may be Reproduced through Practice and Potential for Change**

Though there is ample literature that points to a persistent underemphasis of social and contextual considerations within engineering, there is little research on the mechanisms through which this underemphasis is reproduced, particularly in light of calls for change. Cech's (2014a; 2014b) research suggests that experiences within engineering contexts may serve to lessen engineers' beliefs in the importance of various social and contextual considerations related to engineering work. In a longitudinal study of undergraduate engineering students at four institutions, she 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. Cech's findings raise questions about what specifically is happening within these engineering contexts and the processes through which beliefs about the relative unimportance of social and contextual aspects of engineering work may be reproduced.

I explored the role of day-to-day practice as a potential mechanism for perpetuating dominant cultural values related to engineering work and my findings suggest how individuals acting in local engineering contexts may reinforce the field's narrow technical focus. Holland and Lave (2001; 2009) foreground how encounters and action within local contexts are the means through which larger-scale social forces, such as widespread ideologies about the "pure" technical nature of engineering work, are reproduced at the local level. Thus, widely held beliefs about what engineers do permeate the day-to-day interactions within engineering education and work contexts. In my study, participants often described socially- and contextually-oriented practices as among the least valued in their particular engineering contexts; these included accounting for the social and cultural context of a problem, demonstrating social awareness and empathy in interactions with others, accounting for the natural environment, and integrating perspectives from other fields. Social practice theory suggests that these cultural values are perpetuated by providing a template of what practice looks like in a given setting; thus engineers in particular settings learn that to do engineering and to be readily recognized as an engineer, one's practice of engineering should resemble the culturally valued forms of practice in that setting. If these contextual forms of engineering practice are undervalued and underemphasized by those in a particular engineering community, individuals will likely learn that foregrounding these elements in their own work is not a productive or meaningful way to signal their own position within that community.

Given participants' reports of the lack of attention to contextual aspects of engineering in the engineering settings in which they participate, one would expect that participants' own engineering problem solving would similarly reflect a lack of attention to contextual aspects of engineering work. To examine this relationship, I analyzed the various factors to which 46 engineering students and practitioners attended in their own work solving complex engineering problems. Unsurprisingly, given the nature of engineering work, nearly all participants described attending to technical aspects of engineering work in the projects they worked on. A majority also described accounting for a variety of factors related to the immediate conditions and constraints of a project, including material resources, project timelines, immediate context or setting in which a solution might be deployed, and the provided specifications or requirements. Less than half of all respondents, however, described accounting for stakeholder needs and perspectives and accounting for future iterations on or use of their solutions. Fewer participants, though still more than a third, described accounting for team dynamics and staffing and for the ways various project components were connected or interrelated with one another. Consistent with expectations given the generally low emphasis on contextually-related practices in the engineering settings described by participants in this study, the smallest number of participants described attending to contextual factors, such as the environmental impact, prior work and solutions, the political or economic context, and the cultural or social context, when addressing a complex problem in their field. In this way, most engineers' practice mirrors the dominant cultural values of the field.

Interviews with participants about the experiences that shaped their attention to various factors when solving complex engineering problems converge with the findings emerging from my participants' reports in the card sort interviews regarding valued and devalued engineering practices within their local contexts. I found that most participants did not have prior experiences that encouraged them to consider contextual aspects of their work, including the cultural or social context, environmental impacts, the political or economic context, and future and past-related considerations. Participants more frequently cited prior experiences, whether in educational, work, or professional settings, that focused on technical aspects of their work, followed by team coordination, factors related to the immediate conditions and constraints surrounding a problem, and the perspectives and needs of stakeholders. However, when most participants spoke of stakeholders, they spoke of those most immediately connected to the outcome of a project, such as a client, customer, or sponsor, rather than those who might be less directly affected. While participants often identified course experiences relating to technical details of a problem and attending to provided specs or requirements, experiences related to more human-centered aspects such as team coordination and stakeholder needs often came from out-of-class or workplace or personal experiences. For contextual factors, participants most commonly cited co-curricular and personal experiences as informing their attention to these aspects. In contrast, statistical analyses from the Engineer of 2020 study suggested the engineering curriculum had a stronger relationship with undergraduate students' reports of their levels of contextual competence than did instructional practices or co-curricular activities (Lattuca et al., 2014), suggesting curricular interventions may be necessary in engineers' development of contextual awareness.

The cases of the four participants highlighted in Chapter 6 provide further insight into how the emphases of various contexts differently shape engineers' practice within them. Nelson and Alek, who placed a low degree of personal emphasis on contextual aspects of engineering work, described participating in contexts where such factors were not highly emphasized or valued. In describing their own work addressing a complex engineering problem within those spaces, both men described attending primarily to technical, interpersonal, and more proximal factors, but explicitly mentioned that they did not perceive contextual considerations to be relevant to their work and thus did not account for them in their own practice. In contrast, Leah and Emerson, who were passionate about the contextual dimensions and impact of their engineering work, described feeling constrained in their abilities to account for such aspects in their practice within the engineering contexts they described. While Emerson explained that he felt the format of his course simply did not allow for such considerations, Leah explained that her workplace actively discouraged her from raising social and contextual considerations related to her project.

Based on these findings, I submit one way in which the primacy of technical considerations and the undervaluing of social and contextual aspects is reproduced within engineering. When engineers engage across local contexts that typically undervalue and underemphasize contextual dimensions of engineering, they learn through their interactions in those contexts that attention to social and contextual aspects of engineering is not rewarded or recognized in most engineering settings. Engineers who never participate in an engineering setting in which these contextual aspects *are* emphasized do not have the opportunity to learn that contextual considerations are an important part of engineering work. Neither do they have the opportunity to develop relevant skills and knowledge to address contextual aspects in their own practices. Moreover, engineers whose experiences are limited to engineering contexts that value a narrowly technical image of engineering work typically come to learn and accept that technical work is "real" engineering work and may resist or struggle with, at least initially, integrating contextual aspects into their practice in settings in which they are encouraged to do so. Those engineers who value and are versed in accounting for social and contextual aspects of engineering work may find themselves in situations in which social and contextual aspects are not valued and find, within such settings, that they are discouraged, either implicitly or explicitly, to not attend to these aspects in their own practice. Local contexts in which social and contextual aspects of engineering work are valued may facilitate engineers' attention to these aspects in their own practice, but study findings suggest while this may occur locally, engineers in these spaces do not perceive such an emphasis to extend to the field of engineering more broadly.

How then, might the field of engineering see true change in the form of widespread acknowledgement and accounting for the social and contextual influences on and impacts of engineering work? In my study, participants who reported that they gave attention to contextual aspects of engineering work often cited experiences from their personal life or co-curricular experiences as a source of influence, even though these contextual aspects of engineering practice were not emphasized in the educational and work contexts in which they engaged. This integration of experiences shaped their practice even though it was at odds with the dominant cultural values. Social practice theory suggests that while the dominant cultural values in a context shape activity in that setting, they do not dictate it. People bring with them their own experiences and subjectivities, which Lave and Holland (2001; 2009) dub “history in person,” that shape how they act and make meaning within these contexts. These personal experiences and values have the potential to contribute to gradual change in ideas about the nature of engineering work as they introduce diverse perspectives and viewpoints about the field. For example, one participant described how his experience visiting family in El Salvador, where many citizens lacked access to clean drinking water, ignited for him a personal emphasis on environmental impacts and justice, a passion that he pursued through a personal environmental justice blog while pursuing his doctoral studies as an environmental engineer.

Although my findings suggest that these incremental changes at the local level may be possible, such changes do little to change popular conceptions and values about what engineers do. Though study participants engaged in a range of engineering contexts, the majority described social and contextual elements of engineering work as undervalued in the field. Even many engineers in my study who personally valued and sought out engineering experiences that stressed contextual aspects described these as falling outside the realm of typical engineering work. For real change to occur, more engineers must have a broader repertoire of experiences in which they are encouraged to account for and even foreground contextual considerations in their practice and have the opportunity to develop the skills and knowledge to do so. Facilitating such awareness and skill development would necessarily mean integrating contextual considerations into required engineering courses that all engineers participate in. Cech (2014b) suggests framing a portion of homework and exam questions with a public welfare lens as one means of incorporating these contextual considerations into core curricula and signaling their importance. Increasing an emphasis on social and contextual dimensions of engineering throughout the undergraduate curriculum could help shift understandings of engineering work more broadly, as the undergraduate curriculum serves as the primary means of communicating disciplinary competencies and values and providing experiences that promote the development of these skills and values (Lattuca & Stark, 2009).

### Engineers' Experiences and Consequences of Dominant Cultural Values

Equally important as the question of how narrowly technical views of engineering work are reproduced is how engineers may differently experience and respond to an underemphasis on social and contextual aspects of engineering work. In my study, I sought to understand the extent to which social and contextual aspects of engineering are emphasized in different contexts and how these align with engineers' own values. Prior research suggests that engineering students interested in the socially- or community-oriented aspects of engineering work often describe a disconnect between their interests and the aspects of work emphasized in the field of engineering (Diekman et al., 2011; Gregory & Hill, 2000; Smith et al., 2014). This disconnect may have implications for individuals' perceptions of themselves as engineers or desire to persist in the field. Litchfield and Javernick-Will (2015) found that students engaged in socially-engaged engineering often rejected identifying as typical engineers because of their interests in both technical and social issues related to the field. The authors suggested that participation in engineering contexts better aligned with these students' values might encourage students' interest and persistence in the field. This emphasis and alignment are particularly critical to understand in light of research that suggests engineering work that considers the broader sociocultural context attracts a more diverse population of engineers than more narrowly technical forms of engineering work (Swan, Paterson, & Bielefeldt, 2014).

Existing literature provides some insight into the potential implications for individuals' identification with and interest in engineering based on disconnects between their personal priorities and the aspects of engineering emphasized. However, questions remain about how engineers may think about, navigate, and practice within various engineering settings based on their own values and aspects of engineering emphasized within these settings. In this study, I explored the extent and sources of dissonance described by engineers' related to the cultural values and engineering practices in their local contexts. Here I discuss the experiences, actions, and strategies of engineers who have, at least at the time of our interview, persisted in engineering, organized by whether or not they expressed at least moderate dissonance related to their experiences within engineering. Social practice theory (Holland & Lave, 2001; 2009) characterizes practice in a given context as inherently contested, as the dominant forms of engineering work in that context are subject to negotiation and interpretation by individuals with differing levels of status and power. This status can stem in part from how closely one's own practice aligns with aspects of engineering work most valued within that setting. Such misalignment may then result in individuals not identifying or being identified by others as belonging or fitting in a context or may otherwise be denied power and status within those communities.

Participants in my study described different levels of alignment between their personal values and the aspects of engineering work emphasized in their educational and/or professional engineering settings. Findings from the card sort interviews identified patterns of dissonance and the sources of this dissonance. Examining these patterns revealed differences among participants themselves. Five of the 18 participants who participated in the card sort interviews described very little dissonance between the personal values they held regarding engineering work and the aspects of engineering emphasized in their educational and professional experiences. Three of these participants were graduate students who described a moderate personal emphasis on contextual aspects of engineering work. Of these three students, two described working in research labs that emphasized social and contextual aspects of engineering work. However, the third participant, who described his engagement with contextual considerations in his undergraduate degree, expressed relief that he did not have to worry about non-academic consequences of his current work, which did not emphasize contextual factors. Only one participant, a first year student, who expressed strongly valuing social and contextual aspects of engineering work described little dissonance. Instead, she expressed hope that these aspects would be taught in her upper level courses. Another participant who described minimal dissonance was Nelson, whose story was described in depth in Chapter 6. He expressed a low degree of personal emphasis on contextual aspects of engineering work, an emphasis that aligned well with the predominantly technical focus of his engineering courses and his project team work, as well as with dominant values in the field at large. Alek, who was categorized as expressing moderate dissonance because of his frustration with the theoretical focus of his undergraduate work, described very high alignment with the emphasis of his current professional engineering work environment and, like Nelson, described a low personal emphasis on contextual aspects of engineering work. Alek and Nelson’s emphasis on the physical and technical aspects of engineering work was well-aligned with prototypical images of engineers as most interested in technical, hands on work, described by Faulkner (2007) and Kant and Kerr (2017). It is perhaps not incidental that both Alek and Nelson, whose personal emphases aligned well both with those of their current engineering contexts and the emphasis on the primacy of technological considerations in the field more broadly, found themselves in positions of authority within their work and project team settings, respectively. Being in such positions provided them with an even greater opportunity to influence the forms of engineering practice emphasized in these spaces. No participants who expressed little dissonance with their current engineering settings described feeling out of place, disengaged, or frustrated within their roles nor did they express any intent to leave the field.

In contrast to these engineers, a majority of participants in the card sort activity reported a moderate to high degree of dissonance between what they personally prioritized and what was emphasized in their engineering education or work experiences. Several of these participants wanted more emphasis on practical technical engineering skills related to building and making. However, the majority of engineers who reported a sense of dissonance cited a desire for a broader focus on the contextual and human-oriented aspects of engineering work was the source of this dissonance. Some of the participants who strongly valued contextual aspects of engineering work, but who described only moderate dissonance, reported currently engaging in engineering environments that placed a higher emphasis on these aspects, though they characterized these environments as a contrast to the majority of their engineering experiences. Other participants who described more extreme degrees of dissonance also described seeking out other opportunities to engage in engineering work well-aligned with their values but also described efforts to disengage in engineering contexts in which they experienced the most dissonance, either in terms of the time and energy they devoted to these spaces or through leaving them altogether. These findings illustrate that engineers may, to an extent, be able to seek out engineering settings that counter dominant values of the field in their valuing of contextual considerations. However, the prevalence of dominant narratives related to the narrowly technical nature of engineering work may still take a toll on those who value contextual aspects of engineering and discourage their full participation in settings not well-aligned with their values.

Participants' stories illustrate how dissonance relating to a lack of emphasis on contextual aspects of engineering shaped their decision making about their careers. A number of participants who highly valued contextual engineering work described both their discontent with engineering contexts that did not emphasize such considerations. Further, they spoke of making future career decisions that facilitated their ability to engage in engineering settings better aligned with their values and avoid those that did not. For example, Dominic, who referred to academic engineering work as "miserable," citing a lack of social awareness among his peers and many faculty and the solitary work that he felt characterized academia, explained that he did not intend to pursue academic engineering work upon completing his degree. Similarly, Leah, whose case was described in detail in Chapter 6, expressed a great degree of frustration about the persistent disconnect between her values and those of the field and even left her job in industry to pursue design research better aligned with her priorities in part due to this frustration. Her story echoes findings by Stevens et al. (2008), who describe the experiences of a talented engineering student who considered leaving the field in part because it was not well-aligned with her interest in advancing social good through engineering work. Danielak, Gupta, and Elby (2014) similarly described the case of a student who perceived himself to not fit within engineering because his personal approach to engineering work conflicted with what he perceived to be the dominant practice of the field.

While these stories emphasize the consequences for misalignment between an individuals' personal values and practice and the dominant cultural values of a context, they also highlight the individual agency individuals have to position themselves strategically and engage in work important to them. Thus, while some engineers may eventually decide to leave the field as a result of such misalignment, others may come up with innovative ways to pursue engineering work in a way that reflects their values and potentially even pushes on the norms and culture of the field. In some instances, individuals can draw their personal histories and values, even in light of a disconnect between these and the dominant values of the settings in which they engage, to create "alternative subjectivities" as a means of redefining for themselves what it means for them to be a member of that community (Holland & Lave 2001; 2009). For example, Emerson acknowledged that the social and contextual aspects of engineering work he personally placed a very high degree of emphasis were not stressed in his coursework or widely valued by his peers. However, he expressed his conviction about the importance of these engineering aspects, framing his own attention to them as an asset and a skill he hoped his peers would also develop. Similarly, despite experiencing substantial dissonance between her personal values and the culture around engineering work in her educational and professional experiences, Leah continued to view herself as a talented engineer and maintained the importance of understanding the larger context and human impacts associated with her engineering work. In part, she attributed the lack of emphasis on these aspects of engineering contexts in which she had engaged as strengthening her own prioritization of social and contextual elements of engineering.

Collectively, participants' accounts of dissonance relating to their personal values and the emphases of the engineering contexts in which they engaged highlight a range of experiences and resulting actions. Some engineers' personal values may already be well-aligned with the dominant cultural values of the engineering contexts in which they engage. These engineers may be less likely to encounter threats to their fit within the field, either as a result of their personal identification or how readily they are recognized and valued by other engineers in those contexts. Those participants who do perceive dissonance between their own engineering practice and dominant cultural values may be more likely to doubt their place in the field or be fully recognized for their work. While some engineers may choose to leave the field as a result, the stories of participants in this study illustrate that it is possible for engineers to experience substantial dissonance but still successfully persist in the field. For some engineers, this may mean being strategic about the engineering contexts in which they engage and/or minimizing time spent in those engineering contexts that do not align well with their personal values. Others (though the groups are not mutually exclusive) may develop "alternative subjectivities" in which they recognize that their personal forms of engineering practice do not reflect the dominant cultural values but are able to redefine for themselves what it means to be an engineer, recognizing the value and legitimacy of their contribution within the field. These engineers, through their own day-to-day practice within engineering settings, challenge narrow images of what engineers do, and may, over time and through collective effort, gradually broaden the recognized and valued forms of practice within the field.

**Limitations**

There were a number of limitations to my study which could be addressed through future research. For one, my study included only a limited number of practitioners, particularly in the card sort interviews that provided insight into the dominant values of engineering workplaces. These engineering workplaces varied widely – from a tool manufacturer, to medical device and testing companies, to engineering education settings. Predictably, participants described very different cultures and practices within these settings. The study may better represent the experiences of engineers studying in research universities, as my sample included a greater number of undergraduate and graduate students from only two universities. Still, the study primarily provided insight into the emphases of individual engineering settings and the common experiences of dissonance described by participants across many of these settings, and more research is needed to be able to characterize dominant cultural values within different engineering industries or disciplines.

In addition, this study only captured engineers' approaches to addressing a single complex engineering problem. Thus, the particulars of these problems undoubtedly influenced the aspects of engineering work participants described accounting for within them, giving only limited insight into their overall practice of engineering work. The factors participants' considered would have likely been different in another problem context. While the factors engineers consider in any given problem will be shaped by the specifics of that problem, additional data on the factors they consider across other problem contexts would contribute a richer understanding of their practice of engineering more broadly. This might be addressed in the future by including an additional interview about a second complex problem or by providing a common scenario to all participants and asking them to describe how they might address it. While a second problem was outside the scope of this study, I did take several measures that I believe provided some more general insight into participants' engineering practice. In the first interviews, I asked participants to compare their problem solving experience discussed in our interview to other problems they had encountered in their careers and the types of factors they typically prioritize when addressing complex problems. In addition, the second interviews provided engineers an opportunity to reflect more broadly on the aspects of engineering work emphasized in their educational and work experiences as well as those practices most important to them. A related limitation of the present study concerns the inherent scope and intricacy of complex problems. Such problems are typically beyond the scope of what any individual may be able to hold in their head in detail and are typically solved in teams, making it difficult to understand the full range of factors considered and decision-making processes within a particular problem. As it was part of our screening criteria, all participants described problems that they addressed in team settings. Thus, it is unlikely any participants could fully identify or recall all of the decisions made over the course of each project nor all the factors that shaped this decision making. As a result, my analyses for this study focused on the practice of individual engineers and the factors they personally attended to in their work, but did not capture the full complexity of team decision making that is typical for problems of the scope projects like those described by participants. A study of teams working on complex engineering problems would likely provide deeper insight into the factors engineers consider, how these are informed and constrained by a particular environment, and how different team members' potentially conflicting values and priorities are negotiated within real local contexts.

Finally, this study was limited in the extent to which I was able to understand how different engineers were affected by the degree to which their personal values and practices (mis)aligned with the dominant cultural values of the engineering contexts in which they engage. Many participants spoke of their feelings of frustration or a lack of fit in their engineering courses or workplaces, and several described how this influenced choices about how they allocated their time and made career choices. However, I did not ask participants to reflect on how the dominant values of a particular engineering field informed their experiences in the field, identities as engineers, and future career plans, which might have influenced my understandings of the ways (mis)alignment between dominant cultural values and personal priorities encouraged or deterred engineers' participation in the field. The goal of my study, however, was to focus on local contexts as the sites where practices and values are enacted because these immediate contexts are likely to be most influential in engineers' day-to-day experiences.

**Implications for Research**

Findings from my study point to a number of directions for future research. First, respondents perceived social and contextual aspects of engineering work to be among the least valued or emphasized in engineering education contexts and similarly cited few formal education experiences related to these aspects of engineering work. Further research is needed to understand the ways these values are communicated within engineering education environments. For instance, what messages about engineering work do students take from what is being emphasized in lectures, course readings, assignments, and assessments? In instances where courses successfully emphasize a broad range of engineering practices, what strategies is the instructor employing related to course content and instruction? How do students respond to these conceptions of engineering work?

In addition, while the current study provides insight into how misalignments between what is emphasized in engineering contexts shapes engineers' perceptions of the field of engineering and their place within it, more research is needed to understand the impact of these experiences on engineers' academic and professional career choices. Mixed methods studies may have the best potential for connecting these aspects of engineers experiences. Interview questions would provide data on how, if at all, engineers' perceptions of how what is emphasized in engineering work aligns with their priorities shape their intentions to persist in the field. A follow-up survey would identify larger patterns related to alignment and persistence intentions and thus the consequences of a narrow technical focus within engineering education environments. Relatedly, the experience of “alternative subjectivities,” potential, described in theory and demonstrated by several participants in this study, is a phenomenon that merits further study. What distinguishes those individuals who successfully create alternative subjectivities and thus find ways to engage authentically in engineering contexts that prioritized different values from their own? What distinguishes these individuals from others who continue to struggle to find their place in the field? How do these different responses affect engineers’ persistence in education and work? At a structural level, how might schools and workplaces support multiple models of who engineers are and what they do? Focused case studies may provide greater insight into models for change. At the individual level, exploring in-depth the experiences of engineers who persist and succeed in the field despite prioritizing underrecognized contextual aspects of engineering work could point to factors that facilitate their success, whether these be personal strategies and attitudes, supports such as mentors or friend groups, or pivotal prior experiences that inform and motivate their work. At an institutional level, studies of colleges or workplaces that develop and promote a wide range of engineering competencies could provide greater understanding of structures, initiatives, leadership approaches, and communication strategies that facilitate this breadth.

More research is needed to understand how, if at all, the emphasis of engineering work may varyingly affect individuals with different social identities. Holland and Lave (2001; 2009) foreground how encounters and action within contentious local contexts are the means through which larger-scale social dynamics, such as racism and sexism, are reproduced at the local level. These large-scale cultural forces serve as a mechanism through which power and status are unevenly distributed at the local level. Thus, widely held beliefs about what engineers do and who they are permeate the day-to-day interactions within engineering education and work contexts, though how these are perceived and negotiated by actors within these spaces may vary substantially. Findings from this study as well as existing literature demonstrate that technical aspects of engineering are perceived to be the core of engineering work, with social and contextual aspects being relegated to the "other" (Cech, 2013; Faulkner, 2007; Nieusma & Riley, 2010, Williams, 2002 ). Faulkner's (2007) work describes how these commonly held definitions of engineering work are gendered, with more recognizable technical forms of engineering consistent with traditionally masculine images. In addition, the field risks further perpetuating racial and gender disparities by not creating space for conversations about power and inequity in engineering (Cech, 2013). A wide scale study focused on understanding patterns related to the forms of engineering practice emphasized by engineers with different social identities, how they perceive their practice of engineering to align with the professional or educational contexts in which they engage, and how these relate to their trajectories within the field could help shed light on how values associated with engineering practice may contribute to inequality within the field.

In addition to research aimed at understanding individuals' experiences of engineering contexts and the personal consequences associated with dissonance between one's personal values and motivations and dominant values of the field, further study is needed related to the impact of underemphasis on contextual considerations within the field on engineering problem solving and solutions. This study highlighted how many engineering contexts underemphasize or discourage a focus on social and contextual aspects of engineering and how this emphasis may help perpetuate a narrow focus within engineering practice. While there are a number of examples of the consequences on the impact of engineering solutions when engineers do not consider aspects such as user needs or the context in which a solution may be utilized (Tenner, 1997), additional research on team dynamics and decision making among those working on complex engineering projects could identify ways to facilitate attention to a wider range of factors. Rather than retrospective studies of engineering failures, an intervention-based study model, in which engineering teams are provided with training and prompts related to a broader range of problem dimensions could provide insight into how engineering practice might be expanded and the ways attention to social and contextual aspects could shape engineering solutions.

**Implications for Practice**

Findings from my study also point to implications for practice within engineering education contexts. Consistent with previous research (e.g., Cech, 2014a; Lattuca et al., 2014; Nieusma & Riley, 2010; Riley, 2008; Stevens et al., 2008), 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. 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. Prior research suggests that technical engineering courses generally do not help students develop knowledge related to contextual and social issues (Kastenberg, Hauser-Kastenberg, & Norris, 2006; Loui, 2006). Educators need effective ways to better integrate a broader range of critical engineering skills, including social and contextual awareness, into their courses. However, because the underemphasis on contextual aspects of engineering is widespread, many faculty likely lack necessary information and resources related to teaching social and contextual awareness in their courses. Indeed, previous research suggests graduate programs generally do not provide adequate preparation for future instructional roles more generally (Golde & Dore, 2001; Tanner & Allen, 2006). Providing faculty with training and resources related to strategies for integrating contextual awareness in their classrooms, such as training offered by the University of Michigan's Center for Socially Engaged Design, may be a critical first step in better preparing engineers to address these aspects in their own work.

Relatedly, my findings echo scholarship that suggests currently, within engineering education, many engineers look to co-curricular experiences or other informal ways of learning to develop skills beyond the technical and theoretical foundations of engineering work (e.g., Bielefeldt, Polmear, Canney, Swan, & Knight, 2018; Fisher, Bagiati, & Sarma, 2014; Lichtfield & Javernick-Will, 2015). Reliance on co-curricular activities or other highly individualized experiences risks contributing to further inequality in educational experiences and outcomes within engineering. In addition, as Cech (2013) points out, relegating non-technical aspects of engineering work as supplemental to the technical "core", reinforces the idea that such elements of engineering work are "other," beyond the domain of essential engineering knowledge. When social and contextual aspects of engineering work are neglected and marginalized, those who value and are motivated by the human and societal impacts of engineering work may be alienated; research suggests these individuals are more likely to be women and minoritized students who are already underrepresented within the field of engineering (Chesler & Chesler, 2002; Colvin, et al., 2012; Fraser et al., 2013; Smith, et al., 2014). While co-curricular activities can be a valuable learning experience for many engineers, such experiences vary widely in their focus and quality and there are few ways of controlling or measuring what students learn in these settings. Further, co-curricular activities are not accessible to all students, particularly those who commute to campus, care for family, spend additional time on their coursework, work to support themselves and their families, or have other limitations on their time. Thus, engineering schools should look to co-curricular experiences as a supplement to the core engineering curriculum, not as the primary means for engineers to develop social and contextual engineering skills.

The ability to work in teams is a critical engineering skill, necessary within co-curricular activities, within many courses, and within engineering industry (ABET, 2017; Passow & Passow, 2017). While many participants in this study identified collaboration with others as highly emphasized and important aspects of engineering work, both within their engineering courses and in their future roles as engineers, they indicated that they received little training provided related to *how* to work effectively with team members. Further, many participants described social awareness and empathy in interactions with others to be among the least valued skills in engineering education contexts. Ensuring students receive explicit instruction and guidelines related to effective and equitable teamwork is particularly critical given the substantial differences that exist across engineers related to what they perceive to be important aspects of engineering work and the inherent conflict in negotiating meaning and practice in these spaces. Enacting changes in what is taught at the college level can help to shape the field of engineering to better align with calls for broadening understandings of engineering work beyond the purely technical. As social practice theory points out, individuals bring with them their prior experiences into new contexts and, as they participate in these contexts and draw on their prior experiences in their practice within these spaces, they help shape the meanings and practice that constitute what it means to be an engineer in those new spaces.

## Conclusion

While many studies of engineering contexts and their effects on students and practitioners within them rightfully focus on the engineering climates in educational and work settings, my findings deepen our understanding of engineering contexts by foregrounding the role of practice and its significance in how engineers perceive the field of engineering and their fit within it. Leveraging social practice theory to foreground the relationships between local cultural meanings and practices, larger societal beliefs about engineering work, and the experiences and practice of engineering work of individuals in those contexts permitted a unique and nuanced exploration of individuals experiences in different engineering contexts. As a result, my study contributes a richer understanding of individuals' experiences of engineering in context and in relation to their personal and academic/professional trajectories. It also highlights the need and potential for change: while most engineers in my study did not view social and contextual elements to be highly valued in engineering, many described a desire for greater emphasis on a broader range of engineering skills. Some acted to integrate social and contextual aspects in their own practice of engineering, thus pressing for change. Promoting research and practice aimed at expanding the focus of engineering work to include social and contextual dimensions has the potential to broaden participation in the field by helping individuals who value these aspects to see themselves represented and to better serve people and societies by ensuring the full impacts of engineering solutions are accounted for in addressing the complex problems that characterize our modern world.

## References

ABET-Engineering Accreditation Commission. (2017). *Criteria for accrediting engineering programs: effective for reviews during the 2018-2019 accreditation cycle.*

Amadei, B., & Wallace, W. A. (2009). Engineering for humanitarian development. *IEEE Technology and Society Magazine, 28*(4) 6–15. doi:10.1109/MTS.2009.934940

Atman, C. J., Adams, R. S., Cardella, M. E., Turns, J., Mosborg, S., & Saleem, J. (2007). Engineering design processes: A comparison of students and expert practitioners. *Journal of Engineering Education, 96*(4), 359.

Bahill, A. T., & Gissing, B. (1998). Re-evaluating systems engineering concepts using systems thinking. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), 28*(4), 516-527.

Baker, S., Tancred, P., & Whitesides, S. (2002). Gender and Graduate School: Engineering Students Confront Life after the B. Eng. *Journal of Engineering Education, 91*(1), 41–47. http://doi.org/10.1002/j.2168-9830.2002.tb00671.x

Becher, T., & Trowler, P. R. (2001). *Academic tribes and territories: intellectual enquiry and the cultures of disciplines. (2nd ed.)* . Open University Press/SRHE.

Bielefeldt, A. R., Polmear, M., Canney, N., Swan, C., & Knight, D. (2018). Ethics education of undergraduate and graduate students in environmental engineering and related disciplines. *Environmental Engineering Science, 35*(7), 684-695.

Bollen, K. A., & Hoyle, R. H. (1990). Perceived cohesion: A conceptual and empirical examination. *Social forces,* 479-504.

Carter, D. F., Dueñas, J. E. R., & Mendoza, R. (2019). Critical Examination of the Role of STEM in Propagating and Maintaining Race and Gender Disparities. In *Higher Education: Handbook of Theory and Research* (pp. 39-97). Springer.

Catalano, G., & Baillie, C. (2006). Engineering, social justice and peace: A revolution of the heart. Proceedings of the 113th ASEE Annual Conference and Exposition. Chicago, IL. Retrieved from https://peer.asee.org/engineering-social-justice-and-peace-a-revolution-of- the-heart

Cech, E. A. (2013). The (mis) framing of social justice: Why ideologies of depoliticization and meritocracy hinder engineers' ability to think about social injustices. In *Engineering Education for Social Justice* (pp. 67-84). Springer.

Cech, E. A. (2014a). Culture of Disengagement in Engineering Education? *Science Technology and Human Values*, *39*(1), 42–72. https://doi.org/10.1177/0162243913504305

Cech, E. A. (2014b). Embed social awareness in science curricula. *Nature*, *505*(7484), 477-478.

Cech, E. A. & Sherick, H. M. (2015). Chapter 9: Depoliticization and the structure of engineering education. In S. H. Christensen, C. Didier, A. Jamison, M. Meganck, C. Mitcham, & B. Newberry (Eds.) *International Perspectives on Engineering Education* (pp. 203 – 216). Springer.

Chesler, N. C., & Chesler, M. A. (2002). Gender-Informed Mentoring Strategies for Women Engineering Scholars: On Establishing a Caring Community. *Journal of Engineering Education*, *91*(1), 49–55. http://doi.org/10.1002/j.2168-9830.2002.tb00672.x

Colvin, W., Lyden, S., & León de la Barra, B. A. (2012). Attracting girls to civil engineering through hands-on activities that reveal the communal goals and values of the profession. *Leadership and Management in Engineering*, *13*(1), 35-41.

Creswell, J. W. (1994). *Research Design: Qualitative and Quantitative Approaches*. Sage.

Cross, N., & Cross, A. C. (1998). Expertise in engineering design. *Research in Engineering Design*, *10*(3), 141-149.

Danielak, B. A., Gupta, A., & Elby, A. (2014). Marginalized Identities of Sense-Makers: Reframing Engineering Student Retention. *Journal of Engineering Education, 103*(1), 8–44. https://doi.org/10.1002/jee.20035

Denzin, N. (1989). Strategies of multiple triangulation. In *The Research Act: A Theoretical Introduction to Sociological Methods*. Prentice-Hall.

Diekman, A. B., Clark, E. K., Johnston, A. M., Brown, E. R., & Steinberg, M. (2011). Malleability in communal goals and beliefs influences attraction to stem careers: Evidence for a goal congruity perspective. *Journal of Personality and Social Psychology, 101*(5), 902.

Emerson, R. M., Fretz, R. I., & Shaw, L. L. (2011). *Writing Ethnographic Fieldnotes (2nd edition).* University of Chicago Press.

Faulkner, W. (2007). “Nuts and Bolts and People”: Gender-troubled engineering identities. *Social Studies of Science, 37*(3), 331–356. https://doi.org/10.1177/0306312706072175

Fisher, D. R., Bagiati, A., & Sarma, S. E. (2014). Fostering 21st century skills in engineering undergraduates through co-curricular involvement. In proceedings of the 121st ASEE Annual Conference & Exposition. Indianapolis, IN. https://peer.asee.org/20514

Flyvbjerg, B. (2001). *Making social science matter: Why social inquiry fails and how it can succeed again*. Cambridge University Press

Frank, M., & Elata, D. (2004). Principles for measuring the capacity for engineering systems thinking. Annual Conference on Systems Engineering Research.

Frank, M., & Israel, T. (2000). Engineering Systems Thinking and Systems Thinking. *Systems Engineering*, *3*(3), 163–168. http://doi.org/10.1002/1520-6858(200033)3:3<163::AID-SYS5>3.3.CO;2-K

Fraser, J. M., Bedoya-Valencia, L., & DePalma, J. L. (2013). Community outreach and engagement through sustainability. In the Proceedings of the 120th American Society of Engineering Education Annual Conference & Exposition, Atlanta, GA. https://peer.asee.org/19318

Gardner, S. K. (2008). Fitting the Mold of Graduate School: A Qualitative Study of Socialization in Doctoral Education. *Innovative Higher Education*, *33*(2), 125–138. http://doi.org/10.1007/s10755-008-9068-x

Godfrey, E. (2014). Understanding disciplinary cultures: The first step to cultural change. *Cambridge Handbook of Engineering Education Research*, 437-455. Cambridge University Press.

Golde, C. M., & Dore, T. M. (2001). At Cross Purposes: What the Experiences of Today's Doctoral Students Reveal about Doctoral Education. *Pew Charitable Trusts*, 1–15.

Golde, C. M., & Walker, G. E. (Eds.). (2006). *Envisioning the future of doctoral education: Preparing stewards of the discipline.* Jossey-Bass.

Good, C., Rattan, A., & Dweck, C. S. (2012). Why do women opt out? Sense of belonging and women's representation in mathematics. *Journal of Personality and Social Psychology*, *102*(4), 700–717. https://doi.org/10.1037/a0026659

Gregory, S. T., & Hill, O.O. "Improving Learning Outcomes for At-Risk Multicultural Community College Students." In S. T. Gregory (Ed.), *The Academic Achievement of*

*Minority Students: Perspectives, practices, and prescriptions*. 491-513. University Press of America

Grohs, J. R. (2015). Developing a measure of systems thinking competency (Doctoral dissertation, Virginia Tech).

Harding, S. (2015). *Objectivity and diversity: Another logic of scientific research.* The University of Chicago Press.

Hausmann, L. R. M., Schofield, J. W., & Woods, R. L. (2007). Sense of belonging as a predictor of intentions to persist among African American and White first-year college students. *Research in Higher Education*, 48(7), 803–839.

Hogan, K., & Weathers, K. C. (2003). Psychological and ecological perspectives on the development of systems thinking. In *Understanding Urban Ecosystems* (pp. 233-260). Springer New York.

Holland, D., & Lave, J. (2001). *History in person: Enduring struggles, contentious practice, intimate identities.* SAR Press.

Holland, D., & Lave, J. (2009). Social practice theory and the historical production of persons. *Actio: An International Journal of Human Activity Theory, (2*), 1–15. Retrieved from http://kuir.jm.kansai-u.ac.jp/dspace/handle/10112/7582

Holland, Lachiotte, Skinner, & Cain (1998). *Identity and agency in cultural worlds.* Harvard University Press.

Irwin, S. (2008). Data analysis and interpretation: Emergent issues in linking qualitative and quantitative evidence. In S. N. Hesse-Biber & P. Leavy (Eds.)*, Handbook of emergent methods (pp. 415-435).* Guilford Press.

Johnson, D. R. (2012). Campus racial climate perceptions and overall sense of belonging among racially diverse women in STEM majors. *Journal of College Student Development*, *53*(2), 336–346. https://doi.org/10.1353/csd.2012.0028

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday problem solving in engineering: Lessons for engineering educators. *Journal of Engineering Education, 95*(2), 139–151.

Jones, S. R., Torres, V., & Arminio, J. (2013). *Negotiating the complexities of qualitative research in higher education: Fundamental elements and issues.* Routledge.

Kant, V., & Kerr, E. (2019). Taking Stock of Engineering Epistemology: Multidisciplinary Perspectives. *Philosophy and Technology*, *32*(4), 685–726. https://doi.org/10.1007/s13347-018-0331-5

Kastenberg, W. E., Hauser-Kastenberg, G., & Norris, D. (2006). An approach to undergraduate engineering education for the 21st century. Paper presented at the 36th Annual Frontiers in Education Conference, San Diego, CA. Retrieved from http://fie-conference.org/fie2006/index.html

Korte, R., Sheppard, S. D., & Jordan, W. (2008). A qualitative study of the early work experiences of recent graduates in engineering. American Society of Engineering Education Annual Conference & Exposition, Pittsburgh, PA. https://peer.asee.org/3520

Lattuca, L. R., & Stark, J. S. (2009). *Shaping the College Curriculum: Academic Plans in Context.* Jossey-Bass.

Lattuca, L. R., Terenzini, P. T., Harper, B. J., & Yin, A. C. (2010). Academic Environments in Detail: Holland's Theory at the Subdiscipline Level. *Research in Higher Education, 51*(1), 21–39. https://doi.org/10.1007/s11162-009-9144-9

Lattuca, L., Terenzini, P., Knight, D., & Ro, H. (2014). *2020 vision: Progress in preparing the engineer of the future.* Retrieved from https://deepblue.lib.umich.edu/handle/2027.42/107462

Lattuca, L. R., Terenzini, P. T., & Volkwein, J. F. (2006). Engineering change: Findings from a study of the impact of EC2000, final report. *ABET Inc*.

Leontiev A.N. (1978) *Activity, Consciousness, Personality.* Prentice Hall.

Litchfield, K., & Javernick-Will, A. (2015). "I Am an Engineer AND": A Mixed Methods Study of Socially Engaged Engineers. *Journal of Engineering Education, 104*(4), 393–416.

Lichtman, M. (2006). Judging and evaluating. In *Qualitative Research: A User's Guide*, (pp. 189-199). Sage.

Loui, M. C. (2006). Ethics and the development of professional identities of engineering students. *Journal of Engineering Education, 94*(4), 383–390. doi: 10.1002/j.2168-9830.2005.tb00866.

Lucena, J., Schneider, J., & Leydens, J. A. (2010). Engineering and sustainable community development. *Synthesis Lectures on Engineers, Technology, and Society, No. 11.*

Maxwell, J. A. (2013). *Qualitative Research Design: An Interactive Approach (3rd edition).* Sage.

Miles, M. B., Huberman, A. M., & Saldana, J. (2013). *Qualitative data analysis: A methods sourcebook.* SAGE Publications, Incorporated.

Moskal, B. M., Skokan, C., Munoz, D., & Gosink, J. (2008). Humanitarian engineering. Global impacts and sustainability of a curricular effort. *International Journal of Engineering Education, 24*(1), 162–174. Retrieved from http://www.ijee.ie/latestissues/Vol24-1/s22_ijee1994.pdf

Museus, S. D., & Maramba, D. C. (2011). The impact of culture on Filipino American students' sense of belonging. *The Review of Higher Education*, *34*(2), 231-258.

Museus, S. D., & Quaye, S. J. (2009). Toward an intercultural perspective of racial and ethnic minority college student persistence. *The Review of Higher Education*, 33(1), 67–94.

Museus, S. D., Yi, V., & Saelua, N. (2017). The impact of culturally engaging campus environments on sense of belonging. *The Review of Higher Education*, *40*(2), 187-215.

National Academy of Engineering (2004). The engineer of 2020: Visions of engineering in the new century. National Academies Press.

National Academy of Engineering. (2017). NAE Grand Challenges for Engineering. Retrieved from https://www.nae.edu/Activities/Projects/grand-challenges-project.aspx

National Science Foundation, National Center for Science and Engineering Statistics. (2019). Women, Minorities, and Persons with Disabilities in Science and Engineering: 2019. Special Report NSF 15-311. Arlington, VA. http://www.nsf.gov/statistics/wmpd/.

Nelson Laird, T. F., Shoup, R., Kuh, G. D., & Schwarz, M. J. (2008). The Effects of Discipline on Deep Approaches to Student Learning and College Outcomes. *Research in Higher Education, 49*(6), 469–494.

Nieusma, D., & Riley, D. (2010). Designs on development: engineering, globalization, and social justice. *Engineering Studies (Vol. 2)*. https://doi.org/10.1080/19378621003604748

Ong, M., Wright, C., Espinosa, L., & Orfield, G. (2011). Inside the double bind: A synthesis of empirical research on undergraduate and graduate women of color in science, technology, engineering, and mathematics. *Harvard Educational Review, 81*(2), 172-209. http://doi.org/10.17763/haer.81.2.t022245n7x4752v2

Palmer, B., Terenzini, P. T., McKenna, A. F., Harper, B. J., & Merson, D. (2011). Design in context: Where do the engineers of 2020 learn this skill. American Society for Engineering Education Annual Conference and Exposition. Retrieved from https://peer.asee.org/23333

Passow, H. J., & Passow, C. H. (2017). What Competencies Should Undergraduate Engineering Programs Emphasize? A Systematic Review. *Journal of Engineering Education, 106*(3), 475–526. https://doi.org/10.1002/jee.20171

Patton, M. Q. (2002). Qualitative research and evaluation methods (3rd ed.). Sage Publications.

Riley, D. (2008). Engineering and social justice. *Synthesis Lectures on Engineers, Technology, and Society, 3*(1), 1-152.

Rittel, H., & Webber, M. (1973). Dilemmas in a general theory of planning. *Policy Sciences, 4(*2), 155–169.

Ro, H. K., Merson, D., Lattuca, L. R., & Terenzini, P. T. (2015). Validity of the Contextual Competence Scale for Engineering Students. *Journal of Engineering Education, 104*(1), 35-54.

Rogers, S. W., & Goktas, R. K. (2010). Exploring engineering graduate student research proficiency with student surveys. *Journal of Engineering Education, 99*(3), 263–278.

Rubin, H. J., & Rubin, I. S. (2011). *Qualitative interviewing: The art of hearing data.* Sage.

Seidman, I. (2006). *Interviewing as qualitative research: A guide for researchers in education and the social sciences (3rd edition).* Teachers College Press.

Senge, P.M. (1990). *The fifth discipline: The art and practice of the learning organization,* Doubleday.

Small, M. L. (2009). `How many cases do I need?': On science and the logic of case selection in field-based research. *Ethnography*, *10*(1), 5–38. https://doi.org/10.1177/1466138108099586

Smart, J., Feldman, K., & Ethington, C. (2000). *Academic disciplines: Holland's theory and the study of college students and faculty*. Vanderbilt University Press.

Smith, J. L., Cech, E., Metz, A., Huntoon, M., & Moyer, C. (2014). Giving Back or Giving Up: Native American Student Experiences in Science and Engineering. *Cultural Diversity & Ethnic Minority Psychology*, *20*(3), 413–429. http://doi.org/10.1037/a0036945

Smith, J. L., Lewis, K. L., Hawthorne, L., & Hodges, S. D. (2013). When Trying Hard Isn't Natural: Women's Belonging With and Motivation for Male-Dominated STEM Fields As a Function of Effort Expenditure Concerns. *Personality and Social Psychology Bulletin*, *39*(2), 131–143. https://doi.org/10.1177/0146167212468332

Stevens, R., Johri, A., & O'Connor, K. (2014). Professional engineering work. *Cambridge Handbook of Engineering Education Research*, 119-137. Cambridge University Press.

Stevens, R., O'Connor, K., & Garrison, L. (2005). Engineering student identities in the navigation of the undergraduate curriculum. American Society for Engineering Education Annual Conference & Exhibition, Portland, OR.

Stevens, R., O'Connor, K., Garrison, L., Jocuns, A., & Amos, D. M. (2008). Becoming an engineer: Toward a three dimensional view of engineering learning. *Journal of Engineering Education*, *97*(3), 355-368.

Swan, C., Paterson, K., & Bielefeldt, A. R. (2014). Community engagement in engineering education as a way to increase inclusiveness. *Cambridge Handbook of Engineering Education Research*, 357-372. Cambridge University Press.

Tanner, K., & Allen, D. (2006). Approaches to biology teaching and learning: On integrating pedagogical training into the graduate experiences of future science faculty. *CBE Life Sciences Education*, *5*(1), 1–6.

Tenner, E. (1997). *Why things bite back: Technology and the revenge of unintended consequences.* Vintage. New York, NY.

Tonso, K. L. (2006). Student Engineers and Engineer Identity: Campus Engineer Identities as Figured World. *Cultural Studies of Science Education (Vol. 1).* http://doi.org/10.1007/s11422-005-9009-2

Tonso, K. L. (2014). Engineering identity. *Cambridge Handbook of Engineering Education Research*, 267-282. Cambridge University Press.

Trevelyan, J. (2007). Technical coordination in engineering practice. *Journal of Engineering Education*, *96*(3), 191-204.

UNESCO. (2010). Engineering: Issues, challenges and opportunities for development. Paris, France: UNESCO. Retrieved from http://unesdoc.unesco.org/images/0018/001897/189753e.pdf

Walton, G. M., & Cohen, G. L. (2007). A question of belonging: Race, social fit, and achievement. *Journal of Personality and Social Psychology, 92*, 82-96. doi:10.1037/0022-3514.92.1.82

Weiss, R. S. (1994*). Learning from strangers: The art and method of qualitative interview studies.* Simon and Schuster.

Williams, R. (2002). *Retooling: A historian confronts technological change*. MIT Press.

Wilson, D., Jones, D., Bocell, F., Crawford, J., Kim, M., Veilleux, N., Floyd-Smith, T., Bates, R., Plett, M. (2015). Belonging and academic engagement among undergraduate STEM students: A multi-institutional study. *Research in Higher Education,* 1–27.

## Appendix A: First Interview Participant Screening Questionnaire

**Systems Thinking Interview Screening Questionnaire**

Q1 Please select all the degrees you have completed or are in the process of completing and fill in the field of study for each:

| | Completed Degree? | | | Field of Study |
|---|---|---|---|---|
| | Yes (1) | No (2) | In Progress (3) | Please list field: (1) |
| Baccalaureate Degree (BA, BS, etc.) (1) | ○ | ○ | ○ | |
| Master's Degree (MS, MA, MBA, etc.) (2) | ○ | ○ | ○ | |
| PhD or Professional Doctorate (PhD, MD, JD, etc.) (3) | ○ | ○ | ○ | |
| Other (please specify): (4) | ○ | ○ | ○ | |

Q2 Have you worked professionally as an engineer?

○ Yes (1)

○ No (2)

○ No, but I have worked as a co-op/intern (3)

*Display This Question:*
*If Have you worked professionally as an engineer? = Yes*

Q4 How many years have you worked as an engineer?

________________________________________________________________

*Display This Question:*
*If Have you worked professionally as an engineer? = No, but I have worked as a co-op/intern*

Q5 How long have you worked as a co-op or intern engineer?

________________________________________________________________

Q6 Please provide a 2-3 sentence overview of a complex engineering project with which you have had significant involvement in the last 3 years. In this instance, a complex project refers to any project that had multiple potential solutions and for which there were multiple people with different forms of expertise working on multiple facets or components of the project.

________________________________________________________________
________________________________________________________________
________________________________________________________________
________________________________________________________________

Q7 What was the name of the company, organization, or team you worked with on the project described above?

________________________________________________________________

Q8 What was your role on this project?

________________________________________________________________

Q9 What is your gender identity?

________________________________________________________________

Q10 How would you describe your racial/ethnic identity?

________________________________________________________________

Q11 What is your age?

________________________________________________________________

## Appendix B: First Interview Protocol Draft

Thank you for taking the time to talk to me. I'm going to give you some background on how this will work. Our conversation will be recorded and later transcribed. And identifying information will be removed on the transcript and the audio will be kept in a secured location.

- Do you have any questions about the consent form?
- Can I get you to sign it if everything seems okay to you?

The purpose of this interview is to understand your experiences working on a complex engineering problem and the different elements that inform your decision making around that. I'm interested in learning about your individual experiences and perspectives, so there are no right or wrong answers to any of the questions I ask you.

I'll ask follow-up questions so that we can arrive at a deeper understanding of your experiences. I'm going to leave some open time after I ask a question. I won't jump in to clarify a question if there is a pause. I want to give you time to think. We will use a lot of different language around some of the concepts we're talking about that might not be universally used, so if you would like clarification of a question, please do ask me.

Do you have any questions for me before we begin?

*Past Engineering Experiences*

1. Can you please describe your academic and professional experiences leading up to where you are now?
2. What drew you to the field of engineering?
    a. *If Engineering Professional:* What kinds of projects are you working on in your current role? Are they the kinds of projects you hoped to work on? How so? / How do they differ from what you expected?
    b. *If Student:* Is the type of work you're doing in your engineering courses what you hoped you would be doing? How so? / How do they differ from what you expected?
    c. Outside of your role as a [engineering professional/student] do you pursue any other activities related to engineering or where you can draw on your engineering skills?

*Problem/Context*

3. Now I'd like to ask you a series of questions about a particular complex engineering project that you've worked on recently. Feel free to use pen and paper at any point you wish to help illustrate what you're talking about. Later in the interview, I will specifically

ask you to draw, and eventually would like to see a representation of how you see your problem and the related elements.

a. To begin, can you please briefly describe the project that you worked on and your role on the project?
    i. What was the time scale of the overall project?
    ii. Where did the project come from?
    iii. Why do you think the overall project is important? What about the aspect of the project that you worked on?
b. I want to make sure I understand how work on this project was organized - Can you give me an overview of how the team was organized [and how the work you were doing related to other components]?
    i. How was that work coordinated?
    ii. How often were the different members of your team/ different sub-teams interfacing? About what?
    iii. How did you communicate changes in your designs? Was there a formalized process for reporting changes?
        1. Can you think of any particular instance when you felt you needed to communicate a change or decision about your piece of the project to others right away? What about one that another shared with you?

*Problem Solving Process*

4. What were some key decisions you and your team had to make related to the project? Can you tell me what you ultimately arrived at for those and if you considered other solutions?
    i. What were those other solutions you considered?
    ii. IF SMALL SCALE RESPONSE: How about for the larger project – can you think of any other major decisions that had to be made?
    iii. Did you make suggestions that were not ultimately taken? Did others have other ideas that weren't? Why did [you / the team] decide not to pursue those suggested directions?
    iv. Can you think about any moments where there were conflicting opinions on what the solution should be and what were those about? How did those conflicts play out?
a. Now I want to talk to you about major factors you considered in the **[project description].** When I say factor I mean (requirements, constraints, criteria, inputs etc.). I'm going to ask you to actually list or draw the factors you considered so that we have something we can look at together and refer back to as we discuss them. I'd like to give you a minute to do that and then ask that you talk me through the factors.
    i. *Probes (for major factors):* Why do you feel that factor was important to consider? Did you have any past experiences that suggested that might be an important factor?
    ii. So there are many types of factors that people name as important in solving a problem, including technical specifications, economic aspects, cultural or political aspects, stakeholder needs, previous work in that

area, environmental inputs, future uses of a design, etc. Were there any other factors that you considered that you had not yet named?

iii. When considering all of these factors, were there tradeoffs in what you could account for? Did you prioritize any particular factors? (Were some more important to consider than others in your solution?) What guided that decision?

*Contextual Factors*

b. Under what conditions do you think your solution(s) to your project might look different?
    i. IF SEEKING CLARIFICATION: For example, if you think about how your product was developed, build, deployed, would be disposed of – those types of conditions…
c. I imagine the folks you worked with also shaped how your team addressed the problem. If you could do things your way, how might it have looked different? Would you have emphasized or prioritized different things in addressing the problem?

*Linkages to Academic/Professional Experiences*

5. How similar is the experience you just described to other problems you have worked on?
    a. In these types of problems, are there particular things you typically consider in exploring the problems and potential solutions?
6. Generally speaking, do you think your approach to solving these types of complex problems is similar to or different from other engineers in your field? How so?
    a. Are there types of experiences or training or just things that you value personally that shaped how YOU approached this problem? This could be something from your engineering training or work or from another part of your life entirely unrelated to engineering.
7. What skills and knowledge do you need to be successful at solving a complex problem like the one you described today? (Both personally and generally)
8. What do you think it means to have a systems perspective?
    a. Would you say you are someone who does those things or has a systems perspective?
    b. Do you think how you define a systems perspective is similar to or different from how others in your field would define a systems perspective?
    c. What about compared to others in your company?
    d. …Your educational experiences?

# Appendix C: Codebook

| Category | Code | Code Name | Definition |
|---|---|---|---|
| **Past Experiences** | exp-wk | Work Experience | Any mention of prior professional work experience |
| | exp-int | Co-op or Internship Experience | Any mention of prior co-op or internship work experience |
| | exp-ug | Undergraduate Experience | Any mention of prior undergraduate study experience |
| | exp-grad | Grad School Experience | Any mention of prior graduate study experience |
| | exp-proj | Project Team Experience | Any mention of prior project team experience (like SolarCar or BlueLab) |
| | exp-res | Research Experience | Any mention of prior research experience |
| | exp-pre | Pre-College Experience | Any mention of prior pre-college experiences |
| | exp-pers | Personal Experiences | Any mention of prior personal or non-engineering life experiences |
| | exp-oth | Other Experience | Any mention of prior experiences not included in existing codes |
| | dec-eng | Decision to do Engineering | Explanation of why they became an engineer or their interest in the field |
| | | | |
| **Current Role** | cur-job | Current Job | Mentions or describes current professional role |
| | cur-acad | Current Academic Work | Mentions or describes current academic work |
| | cur-field | Current Field of Study | Mentions or describes current field of study (if student) |
| | cur-team | Current Team Involvement | Mentions or describes current team involvement |
| | cur-otheng | Other Engineering Activities | Mentions or describes other current engineering activities |
| | cur-noneng | Other Non-engineering Activities | Mentions or describes other non-engineering activities |
| | | | |
| **Perceptions of Work** | per-hoped | Work is what hoped | Describes their work or academic experiences as what they hoped they would be |
| | per-diffpos | Work different and positive | Describes their work or academic experiences as different from their expectations, but positive |
| | per-diffneg | Work different and negative | Describes their work or academic experiences as different from their expectations, but negative |
| | per-imp | Work is important | Describes their work or academic work as important |
| | per-unimp | Work is unimportant | Describes their work or academic work as unimportant |
| | per-acad | Work is academic or theoretical | Describes their work as primarily academic research-based, theoretical, or detached from "real world" concerns |

| | | | |
|---|---|---|---|
| | per-apply | Work is applied | Describes their work as having an applied focus or that emphasizes or simulates "real world" applications |
| | per-soc | Work is socially oriented | Describes their work as socially oriented or people minded, particularly in comparison to other engineering work |
| | per-tech | Work is technically oriented | Describes their work as primarily technically oriented |
| | per-lesstech | Work is less technical | Describes their work as less technically oriented than other engineering work |
| | per-noexp | No clear work expectations | Explains they had no real understand or expectation of what their work/academic work would be like |
| | per-align | Alignment | Any instance where participant mentions alignment between their work or values and beliefs related to their work compared to others in their field/engineering |
| | per-diss | Dissonance | Any instance where participant mentions dissonance between their work or values and beliefs related to their work compared to others in their field/engineering |
| | per-oth | Other perceptions about work | Mentions any other perceptions about the nature of their work or academic work |
| | per-self | Self perceptions | Mentions perceptions of self/describes self as possessing particular trait or as a particular sort of person |
| | | | |
| **Emotions** | e-satis | Satisfaction | Expresses satisfaction |
| | e-pride | Pride | Expresses pride |
| | e-pos | Other Positive Emotion | Expresses other positive emotion |
| | e-frust | Frustration | Expresses frustration |
| | e-isolation | Isolation | Expresses feeling isolated or separate from others |
| | e-neg | Other Negative Emotion | Expresses other negative emotion |
| | e-valued | Valued by others | Expresses feeling valued by others, or that their work is valued |
| | e-unvalued | Undervalued by others | Expresses feeling undervalued by others, or that their work is undervalued |
| | | | |
| **Project Description** | proj-descrip | Project overview | Provides overview or description of complex project worked on |
| | proj-role | Role Description | Describes personal role on project |
| | proj-time | Project timescale | Describes timescale of project |
| | proj-origin | Project Origin | Describes the origin of the project / where it came from |
| | proj-impgood | Project Importance - Do good | Explains their project is important because of the potential to do good or have a positive impact on people, society, the environment, etc. |
| | proj-impappl | Project Importance - Application | Explains their project is important because it has a practical application |
| | proj-imptech | Project Importance - Technical | Explains their project is important because it is a novel or important technical problem or advances knowledge |
| | proj-imppers | Project Importance - Personal | Explains their project is important because of the ways it personally affects them or the potential for their and others' learning or growth as engineers |
| | proj-impoth | Project Importance - Other | Explains the project is important for reasons not named above |

| | | | |
|---|---|---|---|
| | proj-roleimp | Project Role Importance | Describes why they feel their role on the project is importance |
| | proj-org | Project Organization | Describes how the project team and work was organized |
| | proj-rolerel | Project Role Relates | Describes how their project role relates to larger work on the project |
| | proj-coord | Project Work Coordinated | Describes how work on the project was coordinated |
| | proj-interface | Frequency Interfacing | Describes frequency team/sub-teams interfaced and about what |
| | proj-commchange | Communicate changes | Describes process or examples of how team communicated changes |
| | | | |
| **Project Decision Making** | dec-descrip | Key Decision | Describes key decisions their team made |
| | dec-solutions | Solutions Considered | Describes other / alternate solutions considered |
| | dec-process | Decision Process | Describes team decision process for decided on a solution |
| | dec-nottake | Suggestions Not Taken | Describes suggestions they or others made that were not taken |
| | dec-conflict | Decision Conflicts | Describes conflicts that arose in project team |
| | dec-res | Conflict Resolution | Describes how conflicts were resolved within the team |
| | | | |
| **Factor Types** | fac-prov | Provided Technical Specs or Requirements | Mentions consideration of technical specs or requirements explicitly provided by sponsor/course/etc. |
| | fac-tech | Technical details of a feature | Mentions consideration of technical details of a problem / aspect of problem |
| | fac-comprel | Relationship between multiple components | Mentions consideration between relationship between multiple problem components |
| | fac-immedcont | Immediate Context | Mentions consideration of the immediate context, such as course or workplace expectations, competition rules, etc. |
| | fac-timeline | Timeline considerations | Mentions consideration of project timeline |
| | fac-resource | Material/financial resources | Mentions consideration of material or financial resources of team |
| | fac-team | Team Dynamics and Staffing | Mentions consideration of the internal team dynamics, including relationships between team members, coordination, and the skills/knowledge/abilities of team members to address problem |
| | fac-manufac | Manufacturability | Mentions consideration of manufacturability of potential solution(s) |
| | fac-enviro | Environmental impact | Mentions consideration of environmental impact of potential solution(s) |
| | fac-cultsoc | Cultural/social context | Mentions consideration of the cultural or social context |
| | fac-stake | Stakeholder needs | Mentions consideration of the stakeholder or Stakeholder needs |
| | fac-polecon | Political or economic context | Mentions consideration of the political or economic context |

| | | | |
|---|---|---|---|
| | fac-temppast | Temporal - past | Mentions consideration of temporal dimensions related to the past / what's been done previously |
| | fac-tempfut | Temporal - future | Mentions consideration of temporal dimension as related to the future - what might be done, sustainability, etc. |
| | fac-other | Other | Mentions consideration of other factor not captured by existing codes |
| | fac-prompted | Mentioned only when prompted | Only mentions factor after prompting (Q 4.a.ii) |
| | fac-unprompt | Mentioned when unprompted | Mentions a factor they accounted for before being asked about factors they considered (even if they do not explicitly identify it as a factor). |
| | fac-irrel | Factor Irrelevant | Mentions a factor or factors are not really relevant to particular project |
| | | | |
| | tradeoffs | Tradeoffs | Mentions tradeoffs in how they were able to account for multiple factors - that a prioritization or accounting for of one factor changed or restricted their ability to account for another |
| | pfac | Priority Factor | Indicates a particular factor is a priority. |
| | cond-tech | Different Conditions - Technical | Suggested solution would look different given different technical factors |
| | cond-ext | Different Conditions - External Constraints | Suggested solution would look different given different external constraints |
| | cond-team | Different Conditions - Team | Suggested solution would look different given different team factors |
| | cond-soc | Different Conditions - Social/Cultural | Suggested solution would look different given different social/cultural factors |
| | cond-res | Different Conditions - Resources | Suggested solution would look different given different resources |
| | cond-time | Different Conditions - Time | Suggested solution would look different given different time-related factors |
| | cond-oth | Different Conditions - Other | Suggestion solution would look different given some other different factor |
| | dodiff | Done Differently | Mentions something they would have liked to do differently to address the problem (but could not due to team) |
| | | | |
| **Link to Past Experience** | prob-sim | Problem Similar | Feels the problem discussed is similar to other problems they've encountered |
| | prob-partsim | Problem Somewhat Similar | Feels the problem discussed is somewhat similar to other problems they've encountered |
| | prob-diff | Problem Different | Feels the problem discussed is different to other problems they've encountered |
| | tcon-sys | Consider system | Describes the system or relationships between multiple components as something they would typically consider in addressing an engineering problem |
| | tcon-req | Consider Requirements | Describes the problem requirements or goals as something they would typically consider in addressing an engineering problem |
| | tcon-const | Consider Constraints | Describes the problem constraints as something they would typically consider in addressing an engineering problem |

| | | | |
|---|---|---|---|
| | tcon-team | Consider Team Dynamics | Describes the team dynamics or relationships between team members as something they would typically consider in addressing an engineering problem |
| | tcon-resource | Consider Resources | Describes the available resources (financial or otherwise) as something they would typically consider in addressing an engineering problem |
| | tcon-stake | Consider Stakeholder(s) | Describes accounting for stakeholder interests or needs as something they would typically consider in addressing an engineering problem. |
| | tcon-other | Consider something else | |
| | | | |
| **Skills and Knowledge** | sk-tech | Technical knowledge | Describes technical knowledge as an important skill |
| | sk-app | Application of tools, techniques, technical skills | Describes the ability to use relevant tools, techniques, or technical applications as an important skill |
| | sk-comm | Communication | Describes communication or interpersonal skills as a key skill |
| | sk-man | Project and time management | Describes project, work, or time management as a key skill |
| | sk-creat | Creativity | Describes creativity as a key skill |
| | sk-soccult | Social/cultural consideration | Describes a consideration of social, people, or cultural factors as a key skill |
| | sk-teamwk | Teamwork and leadership | Describes teamwork and leadership abilities or dynamics as key |
| | sk-temp | Temporal Consideration | Describes a consideration of past and/or present factors, uses, applications, or work as a key skill |
| | sk-syspersp | Systems Perspective | Describes consideration of the system, big picture, relationship between factors/components, etc. |
| | sk-othpersp | Getting others' perspectives | Describes knowing one's own limits and/or seeking ideas, advice, or feedback from others. |
| | sk-perswk | Personal work mindset/ethic | Describes one's personal approach to work - such as perseverance, a growth mindset, commitment to learning, or a strong work ethic - as key |
| | sk-oth | Other | Describes an engineering skill or knowledge not listed above as key. |
| | | | |
| **Systems Thinking** | sys-def | Defines systems | Describes personal definition of systems thinking / what they think it is (or if they do not have a definition) |
| | sys-pers | Personally Systems Thinker? | Assesses whether they are a systems thinker |
| | sys-align | Systems Definition Alignment | Participant explains if and how their systems thinking definition aligns with others' |
| | | | |
| **Other** | other | Other not captured by current codes | |