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Investigating the Habits of Mind of Practicing Engineers

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INVESTIGATING THE HABITS OF MIND OF PRACTICING ENGINEERS

by

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ABSTRACT

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by

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The purpose of this study was to investigate how habits of mind were represented in the work of four practicing engineers working in industry. Current conceptualizations about habits of mind in engineering are taken from an academic approach that is not grounded in engineering practice and primarily focus on the work of undergraduate engineering students. This dissertation study aims to contribute to existing research on habits of mind in engineering by incorporating authentic perspectives from engineers working in practice. The four engineers that participated in this study were purposefully selected across different engineering disciplines, different engineering companies, and different workplace contexts. This study employed a qualitative, comparative case study methodology to develop a deep understanding of how habits of mind were represented in the work of four different engineer cases across different contexts. Qualitative data included field notes from on-site observations at each engineer's workplace; transcripts from interviews and think-aloud sessions with each engineer; notes that were taken during member-checking sessions with each engineer; reflective memos that were written by the researcher about the experience working with each engineer; and information from each engineer's company website and their personal resumes.

Analysis of these data sources revealed that there are five habits of mind that were broadly represented across all four engineer participants. These habits included being *Problem-focused, Interpersonal, Self-reflective, Mindful of the bigger picture,* and *Technically adept.* Findings suggested that these five habits were comprised of individual elements that described the behaviors and ways of thinking that dictated how each habit was represented in the work of each engineer. The ways in which each engineer enacted the five habits of mind differed depending on the context of their work environment, which included the engineering discipline in which they worked, their particular job role and workplace function at their company, and the level of experience within their field. Implications for teaching practice and recommendations for future work exploring habits of mind in engineering are presented. These findings can be used to better prepare undergraduate engineering students to succeed in engineering industry. By understanding how practicing engineers employ habits of mind at the workplace, undergraduate engineering curricula can be intentionally designed to equip students with the intelligent, social behaviors that are used by engineering practitioners.

(283 pages)

PUBLIC ABSTRACT

Investigating the Habits of Mind of Practicing Engineers

Theresa Green

One goal of undergraduate engineering education is to prepare students with the knowledge, skills, and decision-making strategies that are necessary for success in engineering practice. One proposed method to teach students these skills is to incorporate *habits of mind* into K-12 and undergraduate curricula. Habits of mind are the intelligent, social behaviors that engineers should aspire to have when solving problems, engaging with others, and dealing with uncertainty. Previous literature has suggested that incorporating ideas about habits of mind in educational curricula can teach students the disciplinary skills, technical knowledge, and social values that would help prepare them to enter the workforce and society in general. While engineering education researchers have explored how undergraduate engineering students use habits of mind in an academic context, there is little research examining how practicing engineers use habits of mind when solving problems at their workplaces.

The purpose of this study is to explore how habits of mind are represented within the authentic work of practicing engineers working across different engineering contexts. Analysis of field notes, interviews, think-alouds, and artifacts from four distinct practicing engineers suggests that there are five broad habits of mind that are represented across different engineering contexts. The habits of mind include being *Problem-focused, Interpersonal, Self-reflective, Mindful of the bigger picture,* and *Technically adept.*

Findings from this study also suggest that habits of mind are used differently depending on the engineering context. The results of this study can inform curriculum development for undergraduate engineering education to prepare students to enter the engineering workforce by teaching them the engineering habits of mind that are used by practitioners in their field. Additionally, findings support the development of a conceptual framework for habits of mind in engineering for the purpose of guiding pedagogy and curriculum development.

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CHAPTER 1

INTRODUCTION

One goal of undergraduate engineering education is to help students develop the fundamental knowledge, technical skills, and decision-making strategies that are necessary for success in their future careers as practicing engineers (Sheppard et al., 2006). One proposed method to teach students the knowledge, skills, and strategies that will prepare them for professional practice is to incorporate *habits of mind* into K-12 and undergraduate curricula. Habits of mind have been described in the literature as the "intelligent behaviors" (Costa & Kallick, 2008, p. xvi) that people exhibit when solving problems, evaluating arguments, and dealing with uncertainty (Costa & Kallick, 2008; Rutherford & Ahlgren, 1990). Calls for curricular reform in science, mathematics, and engineering suggest that habits of mind can serve as a way to equip students with the disciplinary skills, technical knowledge, and social values that would prepare them to enter the workforce and society in general (e.g. Coll, Taylor, & Lay, 2009; Cuoco, Goldenberg, & Mark, 1996; Katehi, Pearson, & Feder, 2009).

In 1989, the American Association for the Advancement of Science (AAAS) released a report entitled Project 2061: Science for all Americans (Rutherford & Ahlgren, 1990) that set forth recommendations for improving K-12 science education, emphasizing teaching the "understandings and ways of thinking" that "are essential for all citizens in a world shaped by science and technology" (p. xiii). The report advocated for teaching habits of mind as one way to "help students develop the understandings…they need to become compassionate human beings able to think for themselves and to face life head on" (p. xiii). Habits of mind were defined by Project 2061 as the ways in which people make logical decisions, manage uncertainty, and think critically when faced with problems to which they do not know the answers (Rutherford & Ahlgren, 1990). This report conceptualized these habits in terms of values, attitudes, and skills.

Habits of mind are also relevant for teaching in undergraduate engineering education. In 2004, the National Academy of Engineering (NAE) released The Engineer of 2020 (NAE, 2004), a report describing the desirable characteristics that future engineers should have in order to support the ongoing growth and development of the engineering profession into 2020 and beyond. The report suggested that engineering education should equip future engineers with the following attributes: strong analytical skills, practical ingenuity, creativity, good communication, mastery of business and management skills, principles of leadership, high ethical standards, a sense of professionalism, dynamism, agility, resistance, and flexibility (NAE, 2004).

In 2009, the NAE released a report that described the current state of K-12 engineering education in the United States and advocated for incorporating habits of mind into K-12 engineering education curricula (Katehi et al., 2009). To improve and unify the teaching of engineering concepts in K-12 environments, the NAE set forth recommendations for three principles that K-12 engineering education should include:

> Principle 1: Emphasize engineering design,
>
> Principle 2: Incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills, and
>
> Principle 3: Promote engineering "habits of mind" (p. 7).

The NAE stated that the proposed engineering habits of mind are “aligned with what many believe are essential skills for citizens in the 21st century” (p. 7) and include systems thinking, creativity, optimism, collaboration, communication, and ethical considerations. This report from the NAE also described research efforts that explored habits of mind for K-12 engineering education purposes (e.g., Katehi et al., 2009).

Another approach to exploring habits of mind in engineering was taken by researching investigating alternative conceptualizations of habits of mind for use in undergraduate engineering programs (e.g., Lucas & Hanson, 2016). For example, Lucas and Hanson (2016) developed a set of six Engineering Habits of Mind (EHoM) by drawing on terminology describing the engineering profession from engineering accreditation standards (i.e., the UK Standard for Professional Engineering Competence (UK-SPEC) and the European Network for Engineering Accreditation (ENAEE) EUR-ACE Framework) and later validated their interpretations by interviewing practicing engineers. Other researchers have explored how undergraduate engineering students show evidence of using habits of mind as defined by Project 2061 (Rutherford & Ahlgren, 1990) when solving problems in class or while discussing engineering concepts (Johnson et al., 2019; Pitterson, Perova-Mello, & Streveler, 2018; Yellamraju, Magana, & Boutin, 2019).

Several empirical studies (e.g., Pitterson et al., 2018; Yellamraju et al., 2019) in undergraduate engineering contexts have concluded that engineering students exhibit the use of habits of mind when solving classroom problems and discussing engineering concepts with peers. These studies conceptualized habits of mind in terms of values, attitudes, and skills as proposed by Project 2061 (Rutherford & Ahlgren, 1990). Pitterson et al. (2018) argued that, because engineering students demonstrated using habits of mind when solving engineering problems, further investigations of habits of mind in engineering may provide additional insights into how habits of mind could be conceptualized for engineering education. The authors then argued that "habits of mind are not widely studied in engineering though they have been recommended as intended outcomes of engineering education at various levels" (p. 7), such as in The Engineer of 2020 report. Yellamraju et al. (2019) echoed this notion, stating that the aspirations proposed by The Engineer of 2020 (NAE, 2004) include skills that could be fostered if students employed habits of mind when solving complex problems. The authors found that students demonstrated evidence of using habits of mind when creating their own lectures about electrical engineering concepts and providing peer feedback on other students' lectures.

The findings from these studies suggest that habits of mind is a potentially useful yet understudied framework to incorporate into undergraduate engineering curricula to support students in developing the desired knowledge, skills, and attitudes that are described by The Engineer of 2020 (NAE, 2004). Habits of mind can therefore be used by educators to improve undergraduate engineering education to better prepare graduates with the knowledge and skills necessary to both succeed in school and meet the needs of the ever-changing and growing engineering workforce in the future.

1.1 Purpose of the Study

While engineering education researchers have previously explored how undergraduate engineering students use the habits of mind proposed by Project 2061 as they solve academic problems (e.g., Pitterson et al., 2018; Yellamraju et al., 2019), little, if any, research has examined the habits of mind that practicing engineers use when solving problems at their workplaces. *The purpose of this study was to explore how habits of mind are represented within the authentic work of practicing engineers*.

This study contributed to the body of knowledge on habits of mind in engineering and helped to fill the research gap by providing new insights on engineering habits of mind based on the authentic perspectives of engineers working in industry. This study helped to confirm and/or will add to the current conceptualizations on engineering habits of mind posited by the NAE (Katehi et al., 2009) and other engineering education researchers (e.g., Lucas & Hanson, 2016; Pitterson et al., 2018; Yellamraju et al., 2019). Findings from this study will be used to inform curriculum development for undergraduate engineering education to apprentice students in learning the engineering habits of mind that are used by practitioners in their field to better prepare them for the engineering workforce. Additionally, findings may help to provide the basis for future development of a conceptual framework for habits of mind in engineering for the purpose of guiding pedagogy and curriculum development.

1.2 Research Questions

This dissertation study was guided by the following research questions:

1. How are habits of mind represented in the work of practicing engineers?
2. How do habits of mind, as represented through the work of practicing engineers, compare and contrast across engineer case contexts?

1.3 Research Design

This study was conducted using a qualitative case study approach. A qualitative research design allows for an open-ended, inductive approach to data analysis and interpretation while adhering to the context in which the data were situated (Johnson & Christensen, 2017; Miles & Huberman, 1994). This study used a comparative case study methodology with each practicing engineer participant representing a bounded case.

1.3.1 Theoretical Perspective

This study was situated in an interpretivist theoretical perspective using a qualitative comparative case study methodology. An interpretivist paradigm aims to provide descriptions and interpretations of situations, experiences, or phenomena within qualitative research (Jawitz & Case, 2009; Koro-Ljungberg & Douglas, 2008; Lincoln et al., 2011). This paradigm assumes that individuals experience their own lived reality and these realities must be considered when framing a qualitative research study (Lincoln et al., 2011). The interpretivist paradigm is well suited for studies that aim to understand particular phenomena, experiences, or situations as perceived by each individual participant and to provide detailed descriptions about these perceptions (Koro-Ljungberg & Douglas, 2008). Situating this comparative case study within an interpretivist paradigm facilitated an in-depth understanding of the habits of mind within the selected cases to provide “detailed descriptions of their experiences” (Koro-Ljungberg & Douglas, 2008, p.167). Additionally, this paradigm enabled the researcher to account for the multiple lived realities experienced by the participant in each case and promoted a deep understanding of each participant’s reality.

1.3.2 Theoretical Framework

This study was informed by situated learning theory (Lave & Wenger, 1991; Lave, 1991). This theory posits that "learning is recognized as a social phenomenon constituted in the experienced, lived-in world, through legitimate participation in ongoing social practice" (Lave, 1991, p. 64) and that learning is a "process of becoming a member of a sustained community of practice" (Lave, 1991, p. 65). Lave and Wenger (1991) defined a community of practice as the "set of relations among persons, activity, and world, over time and in relation with other tangential and overlapping communities of practice" (p. 98). Thus, according to the situated learning theory, participation in a community of practice inherently contributes to one's learning and understanding of knowledge that is relevant within that community of practice. Members of the community of practice apprentice "newcomers" (Lave, 1991, p.72) into the community by encouraging them to actively participate in the community's activities and teaching them the shared knowledge and skills that are used by "oldtimers" (Lave, 1991, p. 72) in the community.

This study assumed that the engineering discipline is a community of practice with a shared set of values and technical skills. Guided by situated learning theory, this study suggested that one approach to apprenticing undergraduate engineering students into the engineering community of practice is by teaching them the shared values, behaviors, and skills (i.e., the habits of mind) that are used by practicing engineers as the established members of the community. Therefore, the habits of mind that are used by engineering practitioners within the engineering community of practice can be taught to undergraduate engineering students to aid them in becoming more established within the engineering community and better prepare them to enter the engineering workforce.

1.3.3 Conceptual Framework

This study was guided by the habits of mind conceptual framework presented by the Project 2061: Science for All Americans (Rutherford & Ahlgren, 1990) report by the AAAS in addition to the Engineering Habits of Mind (EHoM) identified by engineering education researchers Lucas and Hanson (2016). Several studies in engineering education have used the Project 2061 framework to understand how undergraduate engineering students use habits of mind when discussing engineering concepts with peers and when solving engineering problems in the classroom (Johnson et al., 2019; Pitterson et al., 2018; Yellamraju et al., 2019). This framework describes habits of mind in terms of the values, attitudes, and skills that “relate directly to a person’s outlook on knowledge and learning and ways of thinking and acting” (p. 183). The Project 2061 report argued that science education should aim to promote three particular attitudes and values: curiosity, openness to new ideas, and informed skepticism. Additionally, the report described how certain technical skills comprise the habits of mind framework and are necessary for problem-solving in science. These include computational skills, manipulation and observation skills, communication, and critical-response skills. This habits of mind framework is axiological in nature because it draws upon values and how values are represented in the work of practicing engineers.

Additionally, Lucas and Hanson (2016) recommended a habit of mind framework that could be used to inform K-12 engineering education. Their Engineering Habits of Mind (EHoM) framework was developed by reviewing literature on calls for curriculum reform in K-12 engineering education and drawing upon literature investigating habits of mind in science and mathematics. Lucas and Hanson (2016) validated the EHoM framework by interviewing practicing engineers and obtaining their feedback on how well the habits that they identified from the literature reflected the habits that were used in engineering practice. The items that comprise the EHoM framework (Lucas & Hanson, 2016) include systems thinking, adapting, problem finding, creative problem-solving, visualizing, and improving. These habits of mind are more epistemological in nature than those posed by the Project 2061 framework (Rutherford & Ahlgren, 1990) because they draw upon engineering knowledge and attempt to describe what engineers know and how they know this knowledge.

For this study, habits of mind in engineering were explored using definitions provided by the Project 2061 framework for values, attitudes, and skills, along with the EHoM described by Lucas and Hanson (2016), as a priori codes for data analysis while remaining open to new codes and descriptions within the data. This study combined both the axiological (Project 2061 framework) and epistemological (EHoM framework) habits of mind frameworks to develop a deep understanding of how both types of habits of mind are represented in the work of practicing engineers. Findings from this study are to be used to confirm or supplement current understandings of habits of mind in engineering that have used the Project 2061 framework (Rutherford & Ahlgren, 1990) as well as the EHoM identified by Lucas and Hanson's (2016) review of habits of mind literature by providing perspectives using data collected from the work of practicing engineers. The findings from this study suggest that habits of mind are represented in both axiological and epistemological ways by integrating values, attitudes, and cognitive behaviors in practicing engineers' approaches to solving problems and dealing with uncertainty.

1.3.4 Methodology

A comparative case study methodology was used for this study. This methodology enables the researcher to investigate how a phenomenon manifests across different environments within its real-world context (Stake, 2006; Yin, 2014). The comparative case study methodology was used to examine how the use of habits of mind compare and contrast across practicing engineers working in different contexts, including engineers working in different disciplines, at different companies, and in different job roles. This work resulted in *the first set of engineering habits of mind that is based on data collected directly from practicing engineers*. In this dissertation research, secondary data generated by the dissertation researcher while serving in the role of graduate student researcher in a previous study were used to investigate how habits of mind are represented in the engineers' work. The previous study was funded by the National Science Foundation (NSF) (NSF Award No. EEC 1664228) and explored the literacy practices of practicing engineers.

Over a period of three years, eight practicing engineers participated in the NSF-funded study for six months each; observations were held twice per month and interviews and think-aloud sessions were held once per month. Data collected by the dissertation researcher during the NSF-funded study included two-hour long, in-situ observations of each engineer at each of their workplaces, semi-structured interviews lasting 45-120 minutes, and think-aloud protocol sessions lasting 15-60 minutes. The secondary data used in this dissertation research consists of field notes from the observations, transcriptions from the semi-structured interviews, transcriptions from the think-aloud protocols from four engineers, and resumes from each of the four engineers. In this dissertation study, this secondary data was qualitatively re-analyzed using initial, focused, and axial coding procedures (Saldaña, 2016), in conjunction with new primary data sources, to provide insights into the engineers' habits of mind.

Research quality during data analysis for this dissertation research was ensured through prolonged engagement, persistent observation, member checking, data triangulation, and peer debriefing (Creswell, 2013; Lincoln & Guba, 1985). By conducting two-hour observations twice per month and two-hour interview/think-aloud sessions once per month, each held over the duration of six months with each engineer, the researcher ensured quality in the data collection through prolonged engagement and persistent observation (Creswell, 2013). This experience allowed the researcher to build trust with the participants, learn the culture of the participants' workplace environments, and make judgements about salient data to include from the observations (Lincoln & Guba, 1985). Additionally, research quality was ensured by member checking with the engineer participants. Member checking was performed by presenting and discussing findings with the engineer participants to ensure that the researcher's interpretations of the data accurately represent the engineers' perspectives (Creswell, 2013; Lincoln & Guba, 1985). Research quality was also ensured through triangulating the data using multiple data sources. The multiple sources of data that were collected during this study included the observations, interview and think-aloud transcripts, notes from member-checking sessions, and reflective memos written by the researcher. The analysis of these data sources will help provide corroborating evidence of the findings across the data sources (Creswell, 2013; Lincoln & Guba, 1985; Miles & Huberman, 1994). Additionally, peer debriefing was accomplished by having a peer familiar with qualitative research review the researcher's applied codes on a subset of the data. The peer and the researcher then discussed any discrepancies in the applied codes and interpretations and adjustments were made until a minimum of 80% agreement (Saldaña, 2016) was established.

1.4 Significance of the Study

Prior research (Pitterson et al., 2018; Yellamraju et al., 2019) has explored how academic conceptualizations of habits of mind (i.e., Project 2061) are represented in the work of undergraduate engineering students in the classroom; similar research has not been conducted with practicing engineers in the workplace. This work adds new perspectives, generated from the work of practicing engineers, to the current research on habits of mind in engineering. New insights generated during this study can help inform curricular development in K-12 and in undergraduate engineering education to better prepare students to enter the engineering profession and meet the needs of society.

1.5 Assumptions of the Study

This study used secondary data that were collected for a research project that explored different research questions and was guided by different theoretical and conceptual frameworks than those proposed for this study. The present work assumed that the data collected for this project were appropriate for the analysis performed for this study. Additionally, this study assumed that engineer participants would be able and willing to share accurate accounts of their thought processes that they used to solve authentic workplace problems. This study also assumed that the work the engineers performed while under observation by the researcher was reflective of their general work practices that they would perform when they were not being observed by the researcher. Last, this study assumed that the habits of mind of practicing engineers are aspirational behaviors that others in the engineering education community would want to emulate. The study assumed that the habits of mind framework that was developed for this study can be transformative for engineering education by providing insights into the work of four practicing engineers and that these insights are valuable for the field of engineering education. This study assumed that the habits of mind framework can grow and be expanded as additional, diverse perspectives of engineers working in different contexts continues to be explored.

1.6 Limitations of the Study

This study is limited in several ways. First, this study used data that were collected under another research project that aimed to answer different research questions under alternative theoretical and conceptual frameworks. Different results may be obtained if the interview questions that were used were framed to target habits of mind specifically rather than implicitly. However, this data can still provide valuable insights into the habits of mind of the engineers. For example, when the data were coded for cognitive frameworks that the engineers used when solving workplace problems during the NSF-funded study, the research team found evidence of the engineers making use of *values* and *attitudes* in their solution approaches. These findings suggest that the engineers were using elements of habits of mind as defined by Project 2061 (Rutherford & Ahlgren, 1990) when solving problems and evaluating the solutions.

The second limitation of this study arose from the choice to investigate the habits of mind of four practicing engineers. Further insights about the habits of mind may be identified if a larger population of practicing engineers was investigated. However, considering a small number of engineers allowed for a rich and detailed data collection processes with each participant (Koro-Ljungberg & Douglas, 2008). Emphasis on a small number of participants enabled the researcher to look more deeply into each participant's experience and ultimately strengthened the findings from the case study.

Additionally, this study is limited due to its re-use of data collected from practicing engineers in one region of the western United States. The regional context limited this study in terms of racial, ethnic, and cultural diversity of the participants; all of the practicing engineer participants identified as White and most are members of the local regional culture. Therefore, the lack of racial, ethnic, and cultural diversity among the participants may have limited the behaviors, attitudes, and ways of knowing and thinking in engineering that were observed as the participants approached problems and interacted with others. Thus, the results of this study may not be widely transferable. However, the results from this study may be transferable to other situations that have similar contexts to those of this study (Lincoln & Guba, 1985). The aim of this research is to develop an exploratory, initial understanding of the habits of mind of engineers in general that can be more fully developed with subsequent research among more diverse participants.

Last, this study is limited by the choice of the engineering disciplines that were explored and analyzed. The habits of mind that are exhibited by engineers in the disciplines represented in this study may differ from the habits of mind used by engineers in disciplines that were not explored in this study. However, the disciplines of engineering chosen from this study are among the most common disciplines of engineering based on undergraduate university enrollment and are currently in demand within the engineering workforce (Bureau of Labor Statistics, 2016; National Center for Education Statistics, 2013). Current industry demand for graduates from these disciplines ensures that the findings of this study are robust and can transfer across disciplinary contexts. In addition, the participants selected for this study each work at different levels within their company and thus have different job roles and functions. The engineers selected for this study were purposefully chosen across different job roles to improve the transferability of the findings.

1.7 Definition of Key Terms

Axiology: A philosophical approach that accounts for value-based perspectives and judgements (Lincoln et al., 2011).

Case study research: A qualitative research methodology that seeks to develop an in-depth understanding of a particular phenomenon within a bounded case (Creswell, 2013).

Code: A label, descriptive word, or category name that "symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute" (Saldaña, 2016, p. 4) that the researcher assigns to units of data.

Collective case study: A study that investigates multiple instrumental cases "in order to investigate a phenomenon, population, or general condition" (Stake, 2000, p. 437).

Conceptual framework: A guiding structure that "explains, either graphically or in narrative form, the main things to be studied – the key factors, constructs, or variables – and the presumed relationships among them" (Miles & Huberman, 1994, p. 18).

Epistemology: A philosophical approach that accounts for what is known and how people think about knowledge (Lincoln et al., 2011).

Focused coding: A second-cycle coding approach used to "sift, sort, synthesize, and analyze" (Charmaz, 2014, p. 138) codes generated from the initial coding phase of analysis.

Habits of Mind: A combination of intelligent, social behaviors that engineers should aspire to have when solving problems and facing uncertainty.

Initial coding: A first-cycle coding approach is where the researcher reads the data closely while "remaining open to all possible theoretical directions indicated by your readings of the data" (Charmaz, 2014, p. 114).

Instrumental case study: A case study approach that aims to explore and develop an understanding of a phenomenon that is of interest to the researcher (Stake, 2000).

Member checking: A qualitative validation method where the researcher brings analyses and findings back to the participants to determine their agreement of the "descriptions, explanations, and interpretations" (Miles & Huberman, 1994, p. 48) that the researcher has made from the participant data.

Methodology: The procedures for, identification of, and justifications for choosing a particular set of research methods (Creswell, 2013; Johnson & Christensen, 2017).

Methods: The specific techniques used to obtain or collect the data for a research study (Johnson & Christensen, 2017).

Peer debriefing: The "process of exposing oneself to a disinterested peer…for the purpose of exploring aspects of the inquiry that might otherwise remain only implicit within the inquirer's mind" (Lincoln & Guba, 1985, p. 308). It is a process where an outside individual provides perspectives to the researcher about their analysis and interpretations to "keep them honest" (Creswell, 2013, p. 251; Lincoln & Guba, 1985).

Axial coding: A coding process occurring after initial and focused coding that groups concepts into broader categories and identifies relationships between the categories (R. B. Johnson & Christensen, 2017; Lewis-Beck et al., 2004).

Theoretical framework: The guiding theory from which the researcher aims to understand and plan their research study (Grant & Osanloo, 2014). It is a "structure that guides research by relying on a formal theory…constructed by using an established, coherent explanation of certain phenomena and relationships" (Eisenhart, 1991, p. 205).

Theoretical Perspective: The philosophical assumptions and knowledge basis from which a research study is framed, justified, and analyzed (Jawitz & Case, 2009).

Triangulation: When a researcher uses multiple, independent data sources or methods to show corroboration of findings (Creswell, 2013; Miles & Huberman, 1994).

1.8 Organization of this Dissertation

This dissertation is organized in monograph format consisting of six chapters. Chapter 1 contains the introduction to the study, including the background, purpose, significance, and overview of the research design of the study. Chapter 2 provides a review of the literature relevant to calls for curricular reform in science, mathematics, and engineering and how habits of mind have been proposed as one way to meet these desired curricular changes and educational outcomes. Chapter 3 provides an overview of the research methodology, the methods of data collection and analysis, and approaches for ensuring quality in the research. Chapter 4 presents the results of the study obtained from the data analysis. Chapter 5 presents a discussion of the results situated within current conceptualizations of habits of mind in the engineering education literature. Chapter 6 presents the conclusions of the study, implications for teaching practice, and recommendations for future work.

CHAPTER 2

REVIEW OF THE LITERATURE

One goal of educational programs in general is to "prepare people to lead personally fulfilling and responsible lives" (Rutherford & Ahlgren, 1990, p. xiii) so that they can be active participants in society and contribute intelligently to changing technologies and innovations. Initiatives and calls for education reform (e.g., National Academy of Engineering [NAE], 2004; Partnership for 21st Century Learning, 2019; Rutherford & Ahlgren, 1990) have proposed sets of skills that education should aim to foster in students so they are best prepared to succeed in school, their future workplace, and life in general. One of such initiatives is the framework for learning proposed by The Partnership for 21st Century Learning organization (Partnership for 21st Century Learning, 2019). This framework was developed by educators and business leaders as a vision of the skills and outcomes for learning that would ensure student success in their educational careers and beyond. The Partnership for 21st Century Learning framework consists of following skills:

- Creativity and innovation,
- Critical thinking and problem solving,
- Communication and collaboration,
- Information, media, and technology skills,
- Information literacy,
- Media literacy,
- Life and career skills,

- Flexibility and adaptability,
- Initiative and self-direction,
- Social and cross-cultural skills,
- Productivity and accountability, and
- Leadership and responsibility.

Habits of mind have been conceptualized as one way to prepare students with these skills necessary to be successful in the 21st century (Costa & Kallick, 2008). Costa and Kallick (2008) envisioned a set of 16 habits of mind that could be incorporated into educational curricula to equip students with these skills. An overview of these 16 habits is presented in Table 2-1.

Table 2-1

The 16 Habits of Mind Proposed by Costa and Kallick (2008).

Habit of Mind	**Definition**
Persisting	Not giving up easily; sticking to a task until it is fully completed
Managing impulsivity	Thinking before acting; reflecting before giving an answer
Listening with understanding and empathy	Listening thoughtfully to the perspectives of others; exhibiting empathy toward others' experiences

Thinking flexibly	Maintaining mental flexibility; being open to changing ideas; changing perspectives based on new information
Thinking about thinking (metacognition)	Considering one's own ideas and strategies and reflecting upon the result after implementing them
Striving for accuracy	Carefully reviewing one's work; ensuring adherence to posed criteria and constraints; being open to correcting mistakes
Questioning and posing problems	Asking effective questions; knowing how to ask questions to achieve a desired outcome
Applying past knowledge to new situations	Learning from previous experiences
Thinking and communicating with clarity and precision	Speaking and writing ideas accurately; using appropriate language to convey a desired message; supporting statements with evidence
Gathering data through all the senses	Remaining open to learning from the environment; absorbing information from smell, touch, taste, sight, and sound
Creating, imagining, innovating	Approaching problems from various perspectives; generating new ideas; remaining intrinsically motivated
Responding with wonderment and awe	Enjoying solving problems; seeking challenges; finding beauty in problem-solving
Taking responsible risks	Remaining open to taking chances; thinking differently; embracing spontaneity
Finding humor	Appreciating humor and employing a "whimsical frame of mind" (Costa & Kallick, 2008, p. 35)

Thinking interdependently	Recognizing the importance of working with others; remaining sensitive to others' needs; being open to critical feedback
Remaining open to continuous learning	Striving for lifelong learning; challenging oneself to always learn and grow intellectually

Costa and Kallick (2008) presented theoretical support for their concept of habits of mind from theories on the nature of intelligence and how definitions of intelligence have moved from fixed, aptitude-based abilities toward something that is changeable and can be developed incrementally (e.g., Ennis, 1987; Perkins, 1995; Sternberg, 1984; Whimbey & Whimbey, 1975). Costa and Kallick (2008) argued that intelligence should be defined in terms of a "repertoire of skills" (p. 7) that are able to grow and improve over the course of one's education rather than being fixed entities.

Costa and Kallick (2008) further asserted that educational learning outcomes should reflect the idea of intelligence as a set of skills that can grow over time. They stated that learning outcomes should incorporate habits of mind that encourage students to self-regulate their learning, generate and evaluate alternative solutions to problems, and seek out resources to aid them in problem solving. Additionally, the authors argued that creating a learning environment that encourages students to use habits of mind can help students develop positive attitudes about their intelligence:

> "Children develop cognitive strategies and effort-based beliefs about their intelligence – the habits of mind associated with higher-order learning – when they continually are pressed to raise questions, find solutions that are not

> immediately apparent, explain concepts, justify their reasoning, and seek information. When we hold children accountable for this kind of intelligent behavior, they take it as a signal that we think they are smart, and they come to accept this judgement" (p. 8).

Based on theories on the nature of intelligence that suggested that intelligence is learnable, teachable, and able to grow, Costa and Kallick (2008) concluded that habits of mind can therefore also be "cultivated, articulated, operationalized, taught, fostered, modeled, and assessed" (p. 13) and should therefore be a fundamental component of educational curricula. This theoretical basis supported Costa and Kallick's (2008) rationale for the value habits of mind could have for education in terms of supporting students academically and equipping them with skills that would prepare them for their future careers outside of school. Based on these ideas, Costa and Kallick (2008) proposed the 16 habits of mind presented in Table 2-1.

Similar perspectives about habits of mind as a way to prepare students with essential lifelong skills have been proposed in the science and engineering disciplines (e.g., Katehi et al., 2009; Rutherford & Ahlgren, 1990). In these fields, practitioners must be prepared to handle new technologies, environmental challenges, and globalization considerations that will arise over time (NAE, 2004; Rutherford & Ahlgren, 1990). Recommendations about the skills and attributes that engineers should possess have been outlined in reports specifically targeted toward engineering education. One example is The Engineer of 2020 report released by the National Academy of Engineering (NAE) in 2004. This report described the characteristics that future engineers should have as a result of their engineering education to support the engineering profession into 2020 and beyond (NAE, 2004). Habits of mind have been suggested as one way to prepare engineering students with these skills to ensure student success within the engineering discipline (NAE and National Research Council, 2009).

This literature review describes initiatives that have been proposed to guide curriculum reform for science, mathematics, and engineering education. The review first discusses calls for curricular reform in science and mathematics education and discusses habits of mind as one proposed method for fostering the development of the desired skills proposed by these initiatives. Next, initiatives for engineering education curriculum reform are discussed. Habits of mind are described as one way to address the curricular needs identified by these initiatives. Current conceptualizations of habits of mind within engineering are then described, followed by efforts to introduce and define habits of mind within engineering education specifically. This literature review highlights the need for additional research exploring habits of mind in engineering and will suggest how the current notions of habits of mind in engineering could be supplemented with knowledge about how engineering practitioners use these habits in authentic engineering workplace contexts.

2.1 Call for Curricular Reform: Science and Mathematics

This section includes a review of literature involving calls for curricular reform in science and mathematics and how habits of mind that have been proposed as one way to address the desired outcomes of such reformed curricula. This section then describes how habits of mind have been defined, explored, and incorporated into curricula in science and mathematics.

2.1.1 Project 2061: Science for All Americans

In 1989, the American Association for the Advancement of Science (AAAS) released the report Project 2061: Science for All Americans (Rutherford & Ahlgren, 1990) that set out a call to educators advocating for improving science education. This report emphasized the importance of improving the teaching of science literacy within the United States. The Project 2061 report argued that "most Americans are not science-literate" (p. xv) and that science curricula "emphasize the learning of answers more than the exploration of questions, memory at the expense of critical thought, bits and pieces of information instead of understandings in context, recitation over argument," and "reading in lieu of doing" (p. xvi). To help solve this problem, Project 2061 suggested that science education in the United States should focus on teaching students concepts that foster science literacy and teach science literacy more effectively. Project 2061's definition of science literacy included:

> "Being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the sciences depend on one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics and technology are human enterprises, and know what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes" (p. xvii-xviii).

To achieve this goal, the report outlined a set of recommendations about the "understandings and ways of thinking" that are "essential for all citizens in a world shaped by science and technology" (p. xiii) and that could be integrated into science curricula.

2.1.2 Habits of Mind in Science and Mathematics

One recommendation for curriculum reform suggested by Project 2061 (Rutherford & Ahlgren, 1990) was to include the teaching of *habits of mind* in science.

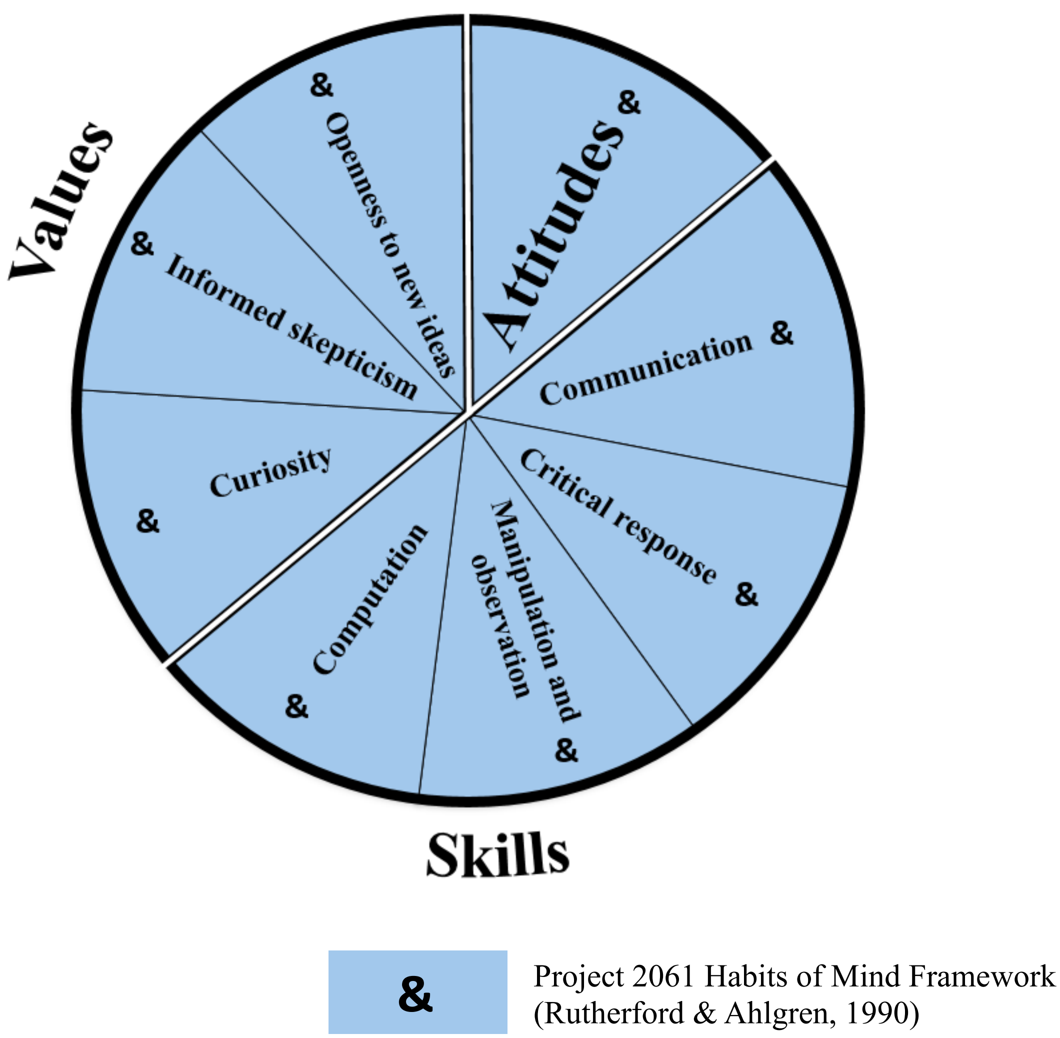
The Project 2061 report suggested that these habits "are essential for science literacy" (p. xviii) and that having a shared set of values, attitudes, and skills among scientists is necessary for students' success in both academic settings and life outside of school. Similar sentiments have been suggested for reforming mathematics curricula (Cuoco, Goldenberg, & Mark, 1996) to "help students learn and adopt some of the ways that mathematicians think about problems" (p. 376) and "develop a repertoire of general heuristics and approaches that can be applied in many different situations" (p. 378). Such a curriculum would encourage students to think more deeply about the content they are learning, equip them with tools to make decisions about solution strategies to use, and understand when these strategies can be applied in new contexts. A curriculum grounded in habits of mind would prepare students to not only succeed in the particular discipline of which they are studying (e.g., science or mathematics), but would also enable them to transfer the general ways of thinking they have learned into other domains or areas of life in general (Cuoco et al., 1996).

Educators have developed several ways in which habits of mind can be conceptualized for informing curricula. For example, Cuoco et al. (1996) described that general habits of mind in mathematics would consist of learning to recognize ill-posed problems; being able to define and ascribe mathematical meaning to problems; systematization, abstraction, or making logical connections; and seeking new ways to describe situations or problems. Project 2061 (Rutherford & Ahlgren, 1990) defined habits of mind in terms of particular values, attitudes, and skills that shape "people's views of knowledge, learning and other aspects of life" (p. 183). An overview of the habits of mind that are included in the Project 2061 framework is presented in

Figure 2-1. The elements of this framework are presented in a light blue color with a (&) symbol.

Figure 2-1

Overview of the Project 2061 Habits of Mind Framework Proposed by the AAAS (Rutherford & Ahlgren, 1990)



As shown in

Figure 2-1, the Project 2061 habits of mind framework was designed to incorporate "values" in terms of the values inherent in science, mathematics, and technology; the social value of science and technology; the reinforcement of general social values; and "attitudes" in terms of people's attitudes toward their own ability to understand science and mathematics (Rutherford & Ahlgren, 1990). The report specified that three of the general social values include "curiosity," "openness to new ideas," and "informed skepticism." Additionally, the skills that comprise habits of mind include "computation and estimation," "manipulation and observation," "communication," and "critical response" to arguments. Definitions for these social values, attitudes, and skills are presented in Table 2-2.

Table 2-2

Habits of Mind Definitions and Conceptualizations as Proposed by Project 2061 (Rutherford & Ahlgren, 1990).

Habits of Mind	Definition	Components
Values	Making decisions about concepts relevant to science and engineering, reinforcing general societal values, and thinking critically about scientific solutions	• **Curiosity:** Asking questions, seeking answers, evaluating the correctness of the answers • **Openness to new ideas:** Considering ideas that are different from one's own or challenge one's beliefs • **Informed skepticism:** Remaining skeptical of new ideas, appreciating the verification and refutal process of new ideas, and maintaining a personal balance between openness and skepticism
Attitudes	Having a positive disposition toward learning science, mathematics, and engineering	• Perceptions of one's knowledge, understanding, and learning and what has informed those perceptions • Taking interest in one's learning and seeking to make meaning of what has been learned

Skills	Applying one's knowledge to problem-solving	• **Computation**: The ability to use computational and estimation skills in meaningful contexts to solve problems • **Manipulation and observation:** The ability to handle physical manipulatives, to make observations, and handling information • **Communication:** The ability to communicate ideas clearly and to read and listen with understanding • **Critical response:** The ability to read and listen to arguments (proposed by self or others) critically and make judgments about what is credible

By inspection, the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990) is seen to assume a more axiological perspective of the behaviors that are used when scientists encounter problems and uncertainty. An axiological approach is concerned with taking value-based perspectives and judgements when making decisions (Lincoln et al., 2011) or considering the value of knowledge itself (de Figueiredo, 2008) during decision making. The components in the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990) incorporate value-based behaviors, such as through the "attitudes" habit of mind or the components of the "values" habit of mind. As shown in

Figure 2-1, the "values" habit of mind is comprised of "curiosity," "informed skepticism," and "openness to new ideas." These components reflect an axiological mindset that would be employed when faced with a problem. They reflect an inclination to uphold personal values in terms of seeking new information, fulfilling personal desires to learn, and being receptive to ideas that conflict with one's own. The "attitudes" habit of mind represents one's desire to learn and the value of learning (Rutherford & Ahlgren, 1990). The presence of this habit of mind further affirms the axiological nature of the Project 2061 framework and the relevance of incorporating value-based perspectives into conceptualizations of habits of mind.

Some of the "skills" presented in the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990) assume a more epistemological perspective. An epistemological perspective aims to understand the nature of knowledge and how knowledge is known (Lincoln et al., 2011). As shown in

Figure 2-1 and Table 2-2, these “skills” incorporate “computation,” “communication,” “manipulation and observation,” and “critical response.” Several of these skills, such as “computation” and “manipulation and observation,” are behaviors that may be a result of knowledge acquisition (epistemological). However, the nature of interpretivist (i.e., constructivist) research, such as that conducted for this dissertation study, suggests that values and knowledge are informed by one another and are difficult to separate (Guba & Lincoln, 1994). Therefore, it is difficult to delineate whether the “skills” in the Project 2061 framework (Rutherford & Ahlgren, 1990) are inherently epistemological or if there are also axiological undertones in these behaviors. The majority of the habits of mind in the Project 2061 framework (Rutherford & Ahlgren, 1990) are explicitly axiological and the framework will be used in this dissertation study in accordance with this observation. However, some elements of this framework may be more knowledge-based in nature and as such, may also incorporate values implicitly.

The framework for habits of mind presented by the AAAS’s Project 2061 report (Rutherford & Ahlgren, 1990) has been investigated and applied by various researchers. Gauld (2005) discussed the “scientific attitude” and corresponding habits of mind that make up this scientific way of thinking. In defining these habits of mind, Gauld’s (2005) work referenced two of the habits of mind outlined in Project 2061 under the habits described by the reinforcement of general social values: open-mindedness and skepticism. Gauld (2005) incorporated these values into the set of habits that contribute to the definition of the scientific attitude. In addition to these two habits, Gauld’s (2005) conceptualization of the scientific attitude in terms of habits of mind also included rationality, objectivity, mistrust of arguments from authority, suspension of belief, and curiosity.

Building from Gauld's (2005) definitions of habits of mind, Coll, Taylor, and Lay (2009) argued that the habits identified by Gauld (2005) could be used to study practicing scientists' ways of thinking, or what they termed "the scientific mind" (p. 725). Coll et al. (2009) proposed that studying habits of mind was essential to understanding science literacy and influencing society's perceptions of science as a field. In their study, Coll et al. (2009) explored the habits of mind of practicing scientists through interviews. This work resulted in evidence that these scientists used the habits of rationality, skepticism, open-mindedness, and mistrust of arguments from authority as defined by Gauld (2005). A similar study by several of these authors suggested that the "scientific attitude" proposed by Gauld (2005) was also evident in their interview responses (Coll & Taylor, 2004), indicating that habits of mind are implicit in the work and attitudes of practitioners.

Informed by these studies of habits of mind in science, Çalik and Coll (2012) described a set of scientific habits of mind (SHOM) to develop the scientific habits of mind survey (SHOMS) to understand the SHOM that are used by students, practitioners, or the general public. When creating the SHOMS, Çalik and Coll (2012) incorporated conceptualizations and definitions for certain habits of mind that were defined by both Project 2061 (Rutherford & Ahlgren, 1990) and Gauld (2005), including: mistrust of arguments from authority; open-mindedness; skepticism; rationality; objectivity; suspension of belief; and curiosity. These studies emphasize the usage of the Project 2061 framework for science education, particularly for guiding educators to use the proposed definitions for habits of mind to inform curricular development and implementation.

In summary, the literature exploring habits of mind for both mathematics and science education has made a call to incorporate teaching these habits within the curriculum. Cuoco et al. (1996) stated, “If we really want to empower our students for life after school, we need to prepare them to be able to use, understand, control, modify, and make decisions” and “help them develop genuinely mathematical ways of thinking” (p. 401). Furthermore, Project 2061 (Rutherford & Ahlgren, 1990) and researchers who subsequently echoed its perspectives (Çalik & Coll, 2012; Gauld, 2005) made a case for teaching habits of mind to strengthen the scientific literacy of students in the United States and better prepare students to succeed in society. Additionally, the literature suggests that understanding habits of mind of practitioners is also valuable for curricular reform and improving science literacy of students (Coll et al., 2009; Coll & Taylor, 2004). The research presented in this section has described the Project 2061 habits of mind framework, the importance of incorporating habits of mind into mathematics and science, and the potential benefits that teaching habits of mind could have for improving scientific literacy among students and citizens.

2.2 Call for curricular reform: Engineering Education

One goal of engineering education is to equip students with the technical knowledge, practical skills, and a sense of professional responsibility that will prepare them to be successful in engineering practice (Sheppard et al., 2006). Engineering students should graduate from their engineering education with the skills necessary for them to meet the demands of the engineering discipline as technology and society evolve over time. To accomplish this, engineering education itself must be able to adapt to these rapid changes and prepare students to be engineers not only within the present landscape of the engineering discipline, but also for the future as the discipline evolves with changing technologies (National Academy of Engineering [NAE], 2004).

In 2004, the National Academy of Engineering (NAE) released The Engineer of 2020 (NAE, 2004), a report that described the challenges that future engineers may face and the characteristics these engineers should have to support the growth and development of the engineering profession into the year 2020 and beyond. This report states,

> "With appropriate thought and consideration, and using new strategic planning tools, we should reconstitute engineering curricula and related educational programs to prepare today's engineers for the careers of the future, with due recognition of the rapid pace of change in the world and its intrinsic lack of predictability" (p. 51).

In order to address the concerns presented in this report about the challenges and changes to the engineering profession that engineers may experience, the report outlined the following desired attributes that engineers in 2020 should possess:

- Strong analytical skills,
- Practical ingenuity,
- Creativity,
- Communication skills,
- Mastery of business and management principles,
- Understand leadership principles,
- Possessing high ethical standards,

- Strong sense of professionalism,
- Dynamism,
- Agility,
- Resilience,
- Flexibility, and
- A desire for lifelong learning.

These attributes aim to characterize engineers in 2020 who "are broadly educated, see themselves as global citizens, can lead in business and public service, as well as in research, development and design," and "are ethical and inclusive of all segments of society" (p. 59).

Similar to the research within the science and mathematics disciplines presented in this literature review, the idea of habits of mind has been proposed as one way to address the calls for curricular reform within the field of engineering education. The notion of incorporating habits of mind into engineering education curricula has been explored in both K-12 and undergraduate settings.

To improve the teaching of engineering within K-12 science, technology, mathematics, and engineering (STEM) curricula, the NAE set forth recommendations to unify the teaching of engineering concepts across K-12 school districts (Katehi et al., 2009). These recommendations included the following principles:

- Principle 1: Emphasize engineering design,
- Principle 2: Incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills, and
- Principle 3: Promote engineering "habits of mind" (p. 7).

The habits of mind included in Principle 3 are systems thinking, creativity, optimism, collaboration, communication, and ethical considerations. The NAE stated that these habits of mind are “aligned with what many believe are essential skills for citizens in the 21st century” (p. 7) and are based on the definition in terms of the values, attitudes, and skills that was provided in the Project 2061 report (Rutherford & Ahlgren, 1990).

2.2.1 Habits of Mind Frameworks in Engineering Education

Two habits of mind frameworks have been used in the engineering education literature to conceptualize and understand how habits of mind are represented in engineering education contexts. These frameworks include the Engineering Habits of Mind (EHoM) framework generated by engineering education researchers (Lucas & Hanson, 2016) and the Project 2061 habits of mind framework proposed by the AAAS (Rutherford & Ahlgren, 1990) as described in Section 2.1.1. The following sections will explore and describe each of these frameworks and how they have been conceptualized for use in engineering education contexts.

2.2.1.1 Use of the Engineering Habits of Mind (EHoM) Framework

Informed by the conceptualizations of habits of mind in mathematics (Cuoco et al., 1996), science (Çalik & Coll, 2012), and those suggested by the NAE for K-12 education (Katehi et al., 2009), Lucas and Hanson (2016) aimed to develop a set of engineering habits of mind (EHoM) that would capture the ways engineers think and act across a variety of engineering disciplines. After performing their own literature review, Lucas and Hanson (2016) proposed six EHoM to inform engineering curricula, including “systems thinking,” “problem finding,” “visualizing,” “improving,” “creative problem-solving,” and “adapting.” The habits within this framework are presented in an orange color with a (x) symbol. An overview of the habits of mind conceptualized in this framework is presented in Figure 2-2. Definitions for each of the six EHoM are presented in Table 2-3.

Figure 2-2

Overview of the Engineering Habits of Mind (EHoM) Framework Proposed by Lucas and Hanson (2016)

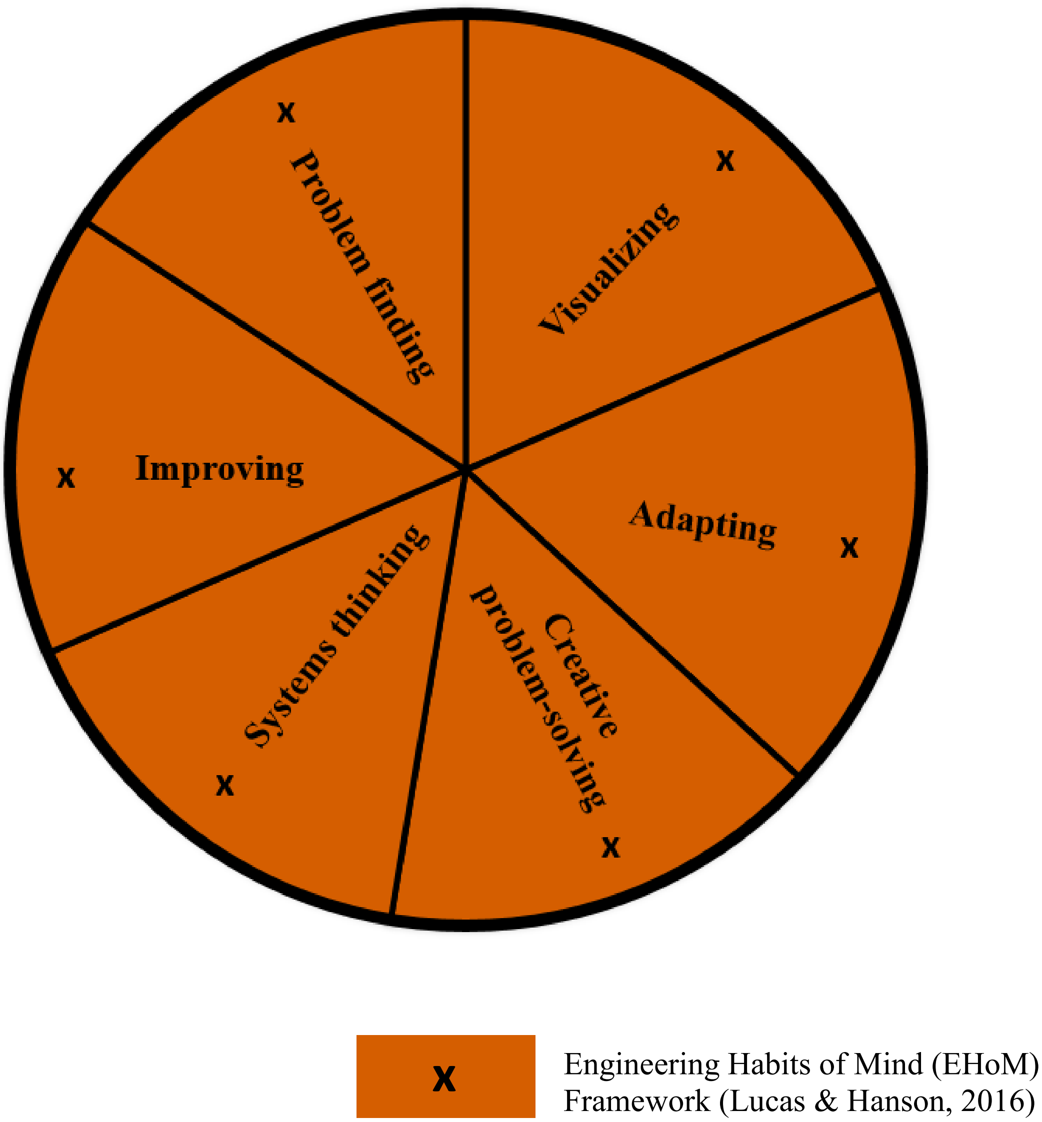


Table 2-3

Engineering Habits of Mind (EHoM) Definitions as Proposed by Lucas and Hanson (2016).

Engineering Habits of Mind (EHoM)	**Definition**
Systems thinking	Seeing whole, systems and parts, and how they connect, pattern-sniffing, recognizing interdependencies, synthesizing
Problem finding	Clarifying needs, checking existing solutions, investigating contexts, verifying
Visualizing	Move from abstract to concrete, manipulating materials, mental rehearsal of physical space and of practical design solutions
Improving	Relentlessly trying to make things better by experimenting, designing, sketching, guessing, conjecturing, thought-experimenting, prototyping
Creative problem-solving	Applying techniques from other traditions, generating ideas and solutions with others, generous but rigorous critiquing, seeing engineering as a “team sport”
Adapting	Testing, analyzing, reflecting, re-thinking, changing (physically and mentally)

To validate these conceptualizations of habits of mind in the EHoM framework, Lucas and Hanson (2016) interviewed practicing engineers to identify whether these habits of mind accurately captured the ways of thinking and acting that they used in engineering practice. Their findings suggested that there was consensus among the practicing engineers about the appropriateness of these habits of mind in terms of how well they described the "characteristic ways in which engineers think and act when faced with challenging problems relating to making and improving things" (p. 6).

The EHoM framework demonstrates an epistemological conceptualization of habits of mind. An epistemological perspective aims to understand what is known and how people think about what is known (Lincoln et al., 2011). The habits of mind in Lucas and Hanson's (2016) EHoM framework are epistemological in nature because they capture cognitive behaviors and ways of knowing applied in engineering problem solving. Habits of mind in this framework, such as systems thinking or visualizing, aim to capture knowledge-based behaviors that are enacted when engaging in engineering work.

2.2.1.2 Use of the Project 2061 Habits of Mind Framework

The habits of mind framework proposed by the American Association for the Advancement of Science (AAAS) in the Project 2061: Science for All Americans report (Rutherford & Ahlgren, 1990) has been used by several researchers in engineering education (K. Johnson et al., 2019; Pitterson et al., 2018; Yellamraju et al., 2019). These studies explored habits of mind defined in terms of values, attitudes, and skills exhibited by undergraduate engineering students while solving problems in the classroom or describing engineering as a field of practice. These studies used this framework because of its implications for supporting science and engineering curricula that incorporate the teaching of technical concepts in addition to supporting students' understanding of how their prior experiences, values, and perceptions about the concept (i.e., their habits of mind) influence their learning (Pitterson et al., 2018).

Using the definitions provided by Project 2061, Johnson et al. (2019) found evidence of values, attitudes, and skills when coding open-ended student survey responses regarding perceptions of engineering as a field practice. The results of this study suggest that values, attitudes, and skills are inherently part of students' understanding of engineering as a field. Additionally, Pitterson et al. (2018) explored the spontaneous habits of mind exhibited by junior- and senior-level undergraduate electrical engineering students using think-aloud protocols. These protocols contained questions that asked students to discuss functions and operations of different components of electrical circuits. Using the definitions for values, attitudes, and skills as outlined in Project 2061, the results from this study suggested that there was evidence of undergraduate engineering students using habits of mind when discussing answers to the think-aloud protocol questions.

Similarly, Yellamraju et al. (2019) characterized the habits of mind of undergraduate engineering students in a signal processing course using the definitions given by Project 2061. In this study, students in the signal processing course were required to create written or video lectures covering course topics and then provide written peer feedback to one another. Using the habits of mind definitions proposed by Project 2061 in terms of values, attitudes, and skills, the authors found evidence of all of these habits when analyzing the written lecture and peer review data.

In summary, the results of these studies suggest that the habits of mind framework presented by Project 2061 is an appropriate way to uncover the values, attitudes, and skills that engineering students use when engaging in discussions about engineering as a discipline, solving engineering problems, and evaluating the quality of problem solutions. Based on these ideas, the literature suggests that the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990) is valuable for studying habits of mind within engineering education because it can provide insights into axiological components of habits of mind that may be present in the work of practicing engineers.

2.3 Summary of Literature Review

In summary, this literature review has described highlighted the need to improve undergraduate engineering curricula; provided background information on how habits of mind have been have been suggested as one way to address the call for curricula improvement; described two conceptualizations of habits of mind in engineering that will serve as guiding frameworks for dissertation study; and has indicated the need for the habits of mind of practicing engineers to be explored to improve undergraduate engineering education.

First, this literature review has described a need for engineering curricula to better prepare undergraduate engineering students to meet the demands of the engineering workforce, both in the present and for the future as technology and society continue to evolve. Engineering education should equip students with the skills necessary to be successful both within school and within the engineering profession as they move throughout their career. This review highlighted literature that has used the idea of habits of mind in engineering as one way to improve engineering education and equip graduates with the skills necessary to contribute to the changing engineering discipline.

This literature review has also provided background information on habits of mind and initiatives that have called for curricular changes to foster student development of these habits of mind. Current conceptualizations of habits of mind for science, mathematics, and both K-12 and undergraduate engineering education were presented. This review provided examples of how habits of mind have been defined and explored in engineering education, all of which were focused on the habits used by undergraduate engineering students in academic contexts.

Guided by the prior research conducted in engineering education, the habits of mind framework presented in the Project 2061 report from the AAAS was chosen as one of the guiding frameworks for this study. This framework was chosen because it informed subsequent calls for incorporating habits of mind into engineering curricula (e.g., Katehi et al., 2009) and has been used in recent studies exploring habits of mind of undergraduate engineering students (K. Johnson et al., 2019; Pitterson et al., 2018; Yellamraju et al., 2019). Additionally, this framework incorporates axiological components of habits of mind. The second guiding framework for this study is the Engineering Habits of Mind (EHoM) framework presented by Lucas and Hanson (2016). This framework was chosen because it uses labels for habits of mind that are more specific to the engineering discipline (e.g., systems-thinking, visualizing, problem finding, etc.). This framework is more epistemological in nature and draws upon the cognitive behaviors and ways of thinking that are employed by engineers. *Taken together, these two conceptualizations provide both axiological and epistemological* *insights from which to explore the habits of mind that are used by engineers working in industry***.** Accounting for these two different perspectives provides a more philosophically and theoretically robust conceptual framework from which to identify and categorize habits of mind in engineering.

Lastly, this review has shown that *there is a need to substantiate the present notions of habits of mind in engineering by exploring how these habits are used in practice by working engineers*. Despite efforts to characterize and identify habits of mind in engineering, there is little evidence in the literature that describes whether the habits identified in the Project 2061 framework (Rutherford & Ahlgren, 1990) or the EHoM framework (Lucas & Hanson, 2016) are apparent in the work of practicing engineers while solving authentic, real-world workplace problems. The Project 2061 framework (Rutherford & Ahlgren, 1990) has been used by engineering education researchers (e.g., K. Johnson et al., 2019; Pitterson et al., 2018; Yellamraju et al., 2019) to explore how undergraduate engineering students use these habits, but there is little, if any, research exploring whether practicing engineers employ these habits of mind as well. Similarly, while the definitions for the EHoM presented by Lucas and Hanson (2016) were validated by interviewing practicing engineers on their perceptions of the definitions, the labels and definitions of the habits themselves were not based on evidence gathered from the work of the practicing engineers.

Investigating how engineering practitioners use habits of mind at the workplace can support students in developing technical engineering knowledge, engineering discipline-specific literacy, skills suggested by The Partnership for 21st Century Learning, and the desired attributes for future engineers as suggested by The Engineer of 2020 report (NAE, 2004; Partnership for 21st Century Learning, 2019; Rutherford & Ahlgren, 1990). By understanding the habits of mind that are used by practicing engineers in the workplace to solve authentic, real-world engineering problems, current conceptualizations of habits of mind for engineering education can be augmented. This study aims to contribute to the literature by exploring the habits of mind employed by practicing engineers while engaged in authentic engineering work. Findings from this study will contribute to current conceptualizations of habits of mind in engineering by confirming and/or supplementing the ideas that have been presented in the current base of literature.

CHAPTER 3

METHODOLOGY

The purpose of this qualitative research project is to explore how habits of mind are represented through the work of practicing engineers. Qualitative research aims to explore a phenomenon as it occurs naturally through inductive research methods (R. B. Johnson & Christensen, 2017). Miles and Huberman (1994) described how qualitative research is "conducted through an intense and/or prolonged contact with a 'field' or life situation" that reflects "the everyday life of individuals, groups, societies, and organizations" (p. 6). A qualitative methodology allows for an open-ended approach to data analysis and interpretation while remaining authentic to the context in which the data were bounded (R. B. Johnson & Christensen, 2017; Miles & Huberman, 1994). By using a qualitative research methodology, this study explored how habits of mind are represented through the work of practicing engineers in their authentic, context-bound environments. This study used a qualitative, comparative case study approach in which each engineer participant represented a bounded case for analysis and exploration (described further in Section 3.7).

3.1 Use of Secondary Data

This dissertation study used secondary data that were collected as part of an NSF-funded research project (Award No. EEC 1664228) for which I, the dissertation study researcher, served as the graduate research assistant. The four-year NSF study aimed to uncover the cognitive frameworks that practicing engineers used to interpret and evaluate information at the engineering workplace. It also aimed to identify the types of texts that practicing engineers wrote, evaluated, and engaged with to fulfill their job functions. The overall goal of the NSF-funded research project was to develop a model representing these types of texts and cognitive frameworks that could then be translated into curricular materials for K-12 students to teach them to use reading and writing strategies that are authentic to the engineering disciplines. This section provides an overview of the NSF-funded project and how the primary data were collected and analyzed.

To accomplish this goal, eight engineers across four disciplines of engineering (i.e., mechanical/aerospace, civil/environmental, electrical/computer, and chemical/biological) were recruited for participation in the NSF study. Each engineer participant was employed at a different company and worked at a different level of product development within their company. Over the three and one-half years, I fulfilled the role of the graduate student researcher and was primarily responsible for all data generation for the project.

In this role, I observed each engineer at their workplace 12 times for a duration of 2 hours per observation session. I took detailed written field notes about the types of texts that each engineer read, wrote, or engaged with, including reports, budgets, design software, emails, presentations, and more. In total, I conducted 96 observations and took 480 pages of typed field notes. Each engineer was also interviewed six times, for a duration of up two hours per interview, about the context, purpose, and quality of the texts they engaged with based on the information captured during the observation sessions.

Additionally, I conducted retrospective think-aloud protocols with the engineers during the interview sessions. During these sessions, engineers were provided with a text that they engaged with during the observation session and were prompted to recount their thought processes that they employed while they were reading, writing, or evaluating the particular text. Interview and think-aloud protocols were written by the Principal Investigator (PI) of the NSF study who holds a Ph.D. in literacy education and is an experienced qualitative researcher. In total, 48 interviews were conducted and 720 typed pages of interview/think-aloud transcripts were generated from this process. Across all eight participants, 288 hours were spent across all eight engineers during the data collection for the NSF study.

The recorded interview and think-aloud data were transcribed through both paid transcribers and through Trint (trint.com), an external, web-based, Institutional Review Board (IRB)-approved transcription service. The paid transcribers all completed trainings on the responsible conduct of research to protect human participants and signed a non-disclosure agreement to protect any sensitive information that they may have heard in the audio files. The Trint service transcribed the audio files using a speech-to-text artificial intelligence software. After transcription, the transcripts were reviewed for accuracy by listening to the original recorded audio and checking and correcting the written transcriptions if needed. The transcriptions were also de-identified to remove names, locations, products, and any potentially identifying information.

The research team for the NSF study jointly analyzed the field notes from the observations and the transcripts from the interview and think-aloud sessions. The team included the PI of the NSF study who holds a Ph.D. in literacy education; the Co-PI of the NSF study, a registered professional engineer who holds a Ph.D. in engineering education; an independent researcher who holds a Ph.D. in curriculum and instruction; a middle school teacher who holds a bachelor's degree in science and a master's degree in education; and myself, the graduate student researcher, who holds bachelor's and master's degrees in mechanical engineering.

Field notes from the observations were first coded by me, the graduate student researcher, and were then back-coded by another member of the research team to mitigate bias in the applied codes. Where there were discrepancies in the codes, the graduate student researcher and the other member of the research team discussed their perspectives until a mutual agreement for which code should be applied was met.

The interview and think-aloud transcripts were analyzed by the PI, the Co-PI, the education researcher, and the graduate student researcher. Each team member independently analyzed each interview/think-aloud transcript to identify themes related to how the engineer interpreted or evaluated information related to their work. The team members then met together to discuss their individual findings and generate a shared understanding of the major themes present in each engineer's interview/think-aloud sessions. The major themes for each of the eight engineers were then translated into a concept map arrangement by the education researcher to provide an overview of the general cognitive frameworks that were used by each engineer. Findings from these analyses were used to inform the development of curricular materials to support K-12 students' learning of authentic engineering practices using cognitive frameworks that were grounded in the work of engineer practitioners working in different disciplines of engineering.

3.2 Conduct of the Dissertation Study

This dissertation study re-used participant observation and interview/think aloud data collected as part of the aforementioned NSF study as secondary data. As the dissertation study researcher, I identified a new topic area for exploration, Engineering Habits of Mind, which was distinct from the topic of the NSF study. Accordingly, I proposed new research questions for this dissertation study. I also adapted the research methodology by applying new theoretical and conceptual frameworks, generating new primary data sources, and conducting separate and distinct data analyses and data validation procedures that were separate from the research questions, frameworks, analysis, and procedures conducted during the NSF study.

Datasets from four out of the eight engineer participants from the NSF study were purposefully selected (described further in Section 3.9.2) for use in the dissertation study. To ethically re-use this data as the dissertation study researcher, I completed and submitted an IRB protocol to distinguish the dissertation study as new and separate from the NSF study. This new IRB protocol enabled me, as the graduate student researcher, to obtain informed consent, separate from that of the NSF study, from the four selected engineer participants. This new informed consent allowed me to use the engineers' data to answer new research questions separate from those used in the NSF study to which they previously consented. The new IRB protocol also documented consent from the four engineer participants to participate in a one-time, virtual member checking session with the researcher to discuss their interpretations and impressions of the dissertation study findings.

3.3 Research Questions

This dissertation study used qualitative inquiry to describe and understand the habits of mind of four practicing engineers working as evidenced through their work within four different contexts. The different contexts represented by each engineer include the engineering discipline in which they work; the companies they work for and their associated context; their individual roles within the company; their level of experience within their discipline; and each engineer's gender identity. This dissertation study was guided by the following research questions:

1. How are habits of mind represented in the work of practicing engineers?
2. How do the habits of mind, as represented through the work of practicing engineers, compare and contrast across engineer case contexts?

3.4 Theoretical Perspective

This study is situated in an interpretivist theoretical perspective. This paradigm assumes that individuals experience their own realities and, as such, there are multiple realities that must be taken into account when framing a research study to ensure that the knowledge produced is reflective of the participants' individual lived realities (Lincoln et al., 2011). This perspective aims to understand particular phenomena, experiences, or situations through detailed descriptions that are situated within the context of the situation or experience (Koro-Ljungberg & Douglas, 2008). Thus, this study was guided by an interpretivist theoretical perspective to account for the multiple lived realities and experiences of each engineer participant in this study.

In order to develop a detailed understanding about a particular phenomenon, studies that are framed by interpretivist perspectives often investigate a small number of purposefully selected participants in order to highlight their unique insights and experiences regarding a certain phenomenon (Koro-Ljungberg & Douglas, 2008). Thus, this study used an interpretivist perspective to investigate the experiences of four engineers, each working at a different company within a different discipline of engineering (i.e. biological, electrical, chemical, and civil engineering), allowing for the individual experiences of each engineer to emerge and provide detailed insights to better inform the study.

3.5 Theoretical Framework

This study was informed by situated learning theory (Lave & Wenger, 1991; Lave, 1991) which posits that "learning is recognized as a social phenomenon constituted in the experienced, lived-in world, through legitimate participation in ongoing social practice" (Lave, 1991, p. 64) and that learning is a "process of becoming a member of a sustained community of practice" (Lave, 1991, p. 65). Lave and Wenger (1991) defined a community of practice as the "set of relations among persons, activity, and world, over time and in relation with other tangential and overlapping communities of practice" (p. 98). According to situated learning theory, individuals learn and generate knowledge by engaging in ongoing participation within a community of practice. Lave (1991) described how "newcomers" (p.72) are apprenticed into communities of practice by actively participating in the community's activities and by being taught the shared knowledge and skills that are used by the "oldtimers" (p. 72) in the community.

Guided by these ideas from situated learning theory, this study assumed that the engineering discipline is a community of practice with a shared set of values and technical skills. Accordingly, this study assumed that engineering students (the "newcomers" (Lave, 1991, p. 72) can be apprenticed into the engineering community of practice by teaching them the shared values, technical skills, and relevant knowledge that are used by experienced members of the community. These shared values, technical skills, and relevant knowledge that were identified from the established community members for this study will be the habits of mind used by those members. For this study, the "oldtimers" (Lave, 1991, p. 72) in the engineering community of practice were considered as the engineer participants that participated in this research.

3.6 Conceptual Framework

This study was guided by a conceptual framework that aims to explain "the key factors, constructs or variables—and the presumed relationships among them" (Miles & Huberman, 1994, p. 18) and provides a structure to connect the different ideas and concepts presented in a study (Grant & Osanloo, 2014). Additionally, a conceptual framework gives the researcher an opportunity to define, specify, and understand each concept in the research individually before integrating the concepts within each other and within the theoretical framework (Luse et al., 2012). The conceptual framework "guides the ways in which you think about collecting, analyzing, describing, and interpreting your data" (Ravitch & Riggan, 2017, p. 17).

This study aimed to understand how habits of mind were represented in the work of practicing engineers and contribute to the body of research that has, to this point, investigated habits of mind from an academic viewpoint. This dissertation study was guided by ideas from two existing habits of mind conceptual frameworks (i.e., Project 2061 (Rutherford & Ahlgren, 1990) and the Engineering Habits of Mind (EHoM) framework (Lucas & Hanson, 2016)) to aid in the processes of interpreting and analyzing the data from practicing engineers in light of the current conceptualizations of habits of mind in engineering contexts. Findings from this study can confirm or supplement these current understandings of habits of mind in engineering with data that is grounded in the work of engineering practitioners.

3.6.1 Project 2061: Science for All Americans Habits of Mind Framework

This study used the habits of mind conceptual framework presented by the American Association for the Advancement of Science's (AAAS) Project 2061: Science for All Americans report (Rutherford & Ahlgren, 1990). This framework defined habits of mind in terms of values, attitudes, and skills that shape the views and perspectives that allow people to be successful in a society that is driven by science and technology. Several researchers in engineering education have used this framework to identify how undergraduate engineering students have used habits of mind in classroom contexts (K. Johnson et al., 2019; Pitterson et al., 2018; Yellamraju et al., 2019). These studies provided evidence that undergraduate engineering students used habits of mind, as defined by Project 2061, when solving problems, discussing solutions with peers, and expressing knowledge about engineering as a field. Therefore, the engineering education literature suggests that using the habits of mind framework proposed in the Project 2061 initiative is valuable for understanding habits of mind in an engineering context. Table

3-1 provides an outline of the habits of mind proposed by Project 2061 and their respective definitions.

This framework aided the researcher in defining and understanding habits of mind axiologically in terms of values, attitudes, and skills. Guided by this pre-defined set of habits of mind, the dissertation researcher was able to identify and provide authentic examples of engineering habits of mind to explain how these habits are represented in the work of the engineering practitioners. The initial conceptualizations for the values, attitudes, and skills provided in the Project 2061 framework served as a priori descriptions to provide a starting point for data analysis while allowing for additional, new conceptualizations about habits of mind to be generated throughout the analysis process.

Table 3-1

Habits of Mind Definitions and Conceptualizations as Proposed by Project 2061 (Rutherford & Ahlgren, 1990).

Habits of Mind	Definition	Components
Values	Making decisions about concepts relevant to science and engineering, reinforcing general societal values, and thinking critically about scientific solutions	• **Curiosity:** Asking questions, seeking answers, evaluating the correctness of the answers • **Openness to new ideas:** Considering ideas that are different from one's own or challenge one's beliefs • **Informed skepticism:** Remaining skeptical of new ideas, appreciating the verification and refutal process of new ideas, and maintaining a personal balance between openness and skepticism
Attitudes	Having a positive disposition toward learning science, mathematics, and engineering	• Perceptions of one's knowledge, understanding, and learning and what has informed those perceptions • Taking interest in one's learning and seeking to make meaning of what has been learned

Skills	Applying one's knowledge to problem-solving	• **Computation**: The ability to use computational and estimation skills in meaningful contexts to solve problems • **Manipulation and observation:** The ability to handle physical manipulatives, to make observations, and handling information • **Communication:** The ability to communicate ideas clearly and to read and listen with understanding • **Critical response:** The ability to read and listen to arguments (proposed by self or others) critically and make judgments about what is credible

3.6.2 Engineering Habits of Mind (EHoM) Conceptual Framework

Additionally, this study incorporated epistemic Engineering Habits of Mind (EHoM) descriptions posited by Lucas and Hanson (2016). The habits of mind these authors identified as salient to the field of engineering included systems-thinking, adapting, problem finding, creative problem-solving, visualizing, and improving. These conceptualizations were drawn from literature calling for curricular reforms for K-12 engineering education and conceptualizations of habits of mind in science and mathematics (Lucas et al., 2014). Descriptions of the EHoM are presented in Table 3-2.

This EHoM framework aided the researcher in developing an understanding of habits of mind in engineering by providing initial conceptualizations and definitions of habits that have been identified in the field of engineering specifically, as opposed to the field of science in general as outlined by the Project 2061 framework (Rutherford & Ahlgren, 1990). The EHoM framework served as an a priori understanding of more specific elements and labels for habits of mind in engineering contexts that were based on concepts from habits of mind literature. By considering this framework for the present study, the researcher was able to compare her findings grounded in the work of practicing engineers, using labels and definitions based on data from authentic engineering environments, to the conceptualizations identified in the EHoM framework that were based on reviews of literature and ideas about habits of mind in science and mathematics.

Table 3-2

Engineering Habits of Mind (EHoM) Definitions as Proposed by Lucas and Hanson (2016).

Engineering Habits of Mind (EHoM)	**Definition**
Systems thinking	Seeing whole, systems and parts, and how they connect, pattern-sniffing, recognizing interdependencies, synthesizing
Problem finding	Clarifying needs, checking existing solutions, investigating contexts, verifying
Visualizing	Move from abstract to concrete, manipulating materials, mental rehearsal of physical space and of practical design solutions
Improving	Relentlessly trying to make things better by experimenting, designing, sketching, guessing, conjecturing, thought-experimenting, prototyping
Creative problem-solving	Applying techniques from other traditions, generating ideas and solutions with others, generous but rigorous critiquing, seeing engineering as a "team sport"
Adapting	Testing, analyzing, reflecting, re-thinking, changing (physically and mentally)

3.7 Comparative Case Study

This study used a collective comparative case study methodology (Stake, 2000). A comparative case study is an approach that examines multiple defined cases in detail to explore how a particular phenomenon is represented throughout each of the cases and how this phenomenon performs in different environments (Stake, 2006). The cases can be defined as individual people, multiple people, events, processes, or industries (Yin, 2018). A collective case study examines multiple instrumental cases to understand a particular phenomenon (Stake, 2000, 2006). Stake (2000) described how instrumental case studies are used to "provide insight into an issue" (p. 437) or facilitate an in-depth understanding about a phenomenon that manifests itself within the case. Yin (2018) described instances for which case study research is appropriate:

> "The more that your questions seek to explain some contemporary circumstance (e.g., "how" or "why" some social phenomenon works), the more that case study research will be relevant. Case studies also are relevant the more that your questions require an extensive and "in-depth" description of some social phenomenon" (p. 33).

Both of the research questions for this study aimed to explore "how" the phenomenon of habits of mind are represented in the authentic work of practicing engineers and "how" these habits compared and contrasted across engineering contexts. This study aimed to develop an in-depth understanding of the context of each case (i.e., each engineer) to determine how habits of mind were represented in those contexts. Therefore, the collective case study methodology was well-suited to help answer the proposed research questions and provide detailed insights about the habits of mind of engineering practitioners in different contexts.

Additionally, case study researchers emphasize that it “is essential” (Agranoff & Radin, 1991, p. 220) to adhere to the context of the cases in order to understand the phenomenon being explored. In contrast to more experimental methodologies, case studies facilitate interpretations and conclusions that are “firmly embedded in the context of the case material” (Agranoff & Radin, 1991, p. 219). Due to the interpretivist perspective guiding this study, a comparative case study methodology therefore helped preserve the authenticity of the environment from which the data were collected in order to understand the unique, context-bound attributes of the selected cases. This approach allowed for a general understanding of habits of mind of practicing engineers to be developed while remaining authentic to each engineer’s workplace role, engineering discipline, and company environment.

Considering multiple cases is also useful for examining how a phenomenon “performs in different environments” (Stake, 2006, p. 23). Agranoff and Radin (1991) argued that comparative case studies are advantageous because “a separate case study for each site allows the researcher to collect data that may be idiosyncratic to that site and provides the base for in-depth interpretation of the context of that site” (p. 218). By considering multiple cases, the comparative case study approach allows for the researcher to explore similarities and differences about how a phenomenon manifests in different environments while being sensitive to the original contexts from which interpretations will be made (Agranoff & Radin, 1991; Stake, 2000, 2006; Yin, 2018). The comparative case study approach therefore allowed the researcher to identify how the habits of mind used by each engineer are similar or dissimilar while recognizing that the unique disciplines, roles, and workplace contexts of each engineer may affect how they used habits of mind.

In summary, a comparative case study methodology was appropriate for this study because it aimed to explore and compare the phenomenon of habits of mind of practicing engineers at different companies and across different disciplines through an in-depth understanding of each engineer's job function, work tasks, and overall workplace environment. Considering multiple cases comprised of different types of engineers in unique workplace contexts provided insights into how habits of mind were employed within each of these contexts. Insights from the analysis of the cases provided an in-depth understanding of how habits of mind were used by practicing engineers and how they were similar or different depending on the context of the engineers' environment.

3.8 Researcher Positionality

One important consideration when conducting qualitative research is the idea of reflexivity. Due to the interpretive nature of qualitative research and the close relationships the researcher has with the participants, it is important for the researcher to recognize their role and influence they have during the research process. As stated by Berger (2015), reflexivity involves a

> "turning of the researcher lens back onto oneself and take responsibility for one's own situatedness within the research and the effect that it may have on the setting and the people being studied, questions being asked, data being collected and its interpretation" (p. 220).

Creswell (2013) echoes this notion by describing how reflexivity allows qualitative researchers to be mindful of the "biases, values, and experiences" (p. 216) that they bring to the study. Thus, it is important for me as the researcher of this study to acknowledge my role and position within this research. Over the past three years while working on my engineering education doctoral degree, I have been working as the graduate research assistant on a National Science Foundation (NSF)-funded research project exploring the literacy practices of practicing engineers in their workplaces. Through the data I collected as part of this study from each engineer and from the analysis that our research team performed on the data, I became interested in the idea of how engineers use habits of mind when conducting their work. In particular, I was interested in the idea of how the engineers made judgements and decisions about complex problems for which there was no single correct answer. Throughout our analysis, our research team found evidence that the engineers maintained a sense of values when they made engineering decisions. These findings foregrounded my interest in exploring how engineers use values (a component of habits of mind) when solving real-world engineering problems. After exploring the concept of habits of mind in general and then reviewing the literature on how habits of mind have been studied in engineering, I found little research exploring how practicing engineers employ habits of mind when solving workplace problems. These ideas motivated me to investigate how the engineers that I worked with as part of the NSF-funded study used habits of mind when working and describing how they solved problems.

Additionally, my prior analysis of the data under the NSF-funded project with the research team may bias my interpretations made from the analysis for this study. While the previous analysis indicated evidence of the engineers making use of values and attitudes, these interpretations were guided by different research questions under another theoretical framework. To mitigate this bias, I was reflexive (Berger, 2015; Creswell, 2013) to ensure that my descriptions about habits of mind were in alignment with my research questions and methodology for this dissertation study and were not influenced by the analyses that I participated in while working on the NSF-funded project.

Last, I acknowledge the interpretive bias that I have due to the fact that I have not practiced in engineering industry. My interpretations of the habits of mind used by the engineers were based on my understanding of what it means to demonstrate habits of mind in conjunction with the a priori definitions I have selected to employ from the literature (e.g., from the Project 2061 framework (Rutherford & Ahlgren, 1990) and the EHoM framework (Lucas & Hanson, 2016)). I also acknowledge that my academic training from my bachelor's and master's degrees is solely in mechanical engineering. My personal perceptions of how engineers enact values, demonstrate certain attitudes, and perform technical skills (i.e., the habits of mind) are informed by my theoretical understanding of how these would be represented in mechanical engineering. As such, I am not familiar with how engineers from other disciplines may conceptualize habits of mind in light of their own discipline. Therefore, the engineer participants themselves may have different perspectives on the definitions for habits of mind that are reflective of their discipline and/or their industry work experiences.

3.9 Participants

This study used data collected with practicing engineers as part of an NSF-funded research project (Award No. EEC 1664228) (see Section 3.1). This section provides an overview of the engineer case selection, descriptions of the engineers that participated in the dissertation study project, and justifications for which engineer data were selected for analysis for this dissertation study.

3.9.1 Dissertation Study Participant Pool

The eight engineers who participated in the NSF-funded study comprised the participant pool from which four engineer cases were purposefully selected for participation in this dissertation study. During the NSF-funded study, purposeful sampling was used to recruit two engineers from four disciplines of engineering, including electrical/computer, mechanical/aerospace, civil/environmental, and chemical/biological for a total of eight engineer participants. These four disciplines of engineering (i.e., electrical/computer, mechanical/aerospace, civil/environmental, and chemical/biological) were chosen because they are commonly offered as majors of study at undergraduate institutions in the United States and because they are in demand nationally by employers (Bureau of Labor Statistics, 2016; National Center for Education Statistics, 2013). These engineers were purposefully selected to represent variety in disciplinary-specific job roles, functions, and workplace environments. Purposeful sampling involves selecting "information-rich cases for study in depth" (Patton, 2002, p. 230). By purposefully selecting which participants or cases to analyze, more in-depth details and understandings can be generated from the data as opposed to broad generalizations about the cases.

These disciplinary engineers were selected for participation based on four criteria. First, the engineers were selected from eight different companies to enhance the ecological validity of the study. Ecological validity is described by the degree to which the results of a study can be extended to other settings (Gravemeijer & Cobb, 2006; R. B.

Johnson & Christensen, 2017; Lewis-Beck et al., 2004). Ecologically valid research aims to represent the considered phenomena occurring in their natural setting as accurately as possible while maintaining the authenticity of the context from which the phenomena are situated (Lewis-Beck et al., 2004). By selecting engineers from eight different companies across different disciplines of engineering, research findings can account for a variety of contexts that would be encountered in engineering practice. Therefore, by enhancing the ecological validity of the study, findings from the study can be more readily transferable to other situations and engineering contexts.

Second, engineers working within different levels of product development were chosen to further enhance the robustness of the data collected. Previous research has suggested that engineers read and communicate in different ways depending on their role in product development (Kwasitsu, 2003; Vest et al., 1996). By selecting engineers across different levels within product development, the findings of the study can account for workplace practices that may appear across different job roles, functions, and disciplines of engineering.

Next, engineers that had experience practicing in industry for at least five years were selected. This selection criterion was used in order to ensure that each engineer participant had experience in their chosen discipline of engineering and were accustomed to engineering ways of thinking in industry. One exception to this criterion was the civil engineer. The civil engineer had been practicing formally as an engineer for three years at the time in which he participated in the NSF study. However, prior to this role, he served as a senior engineering technician for three years where he assisted the engineer in the job role that he held while he participated in the NSF study. This role included tasks and activities that were similar to the types of work that he performed in his formal engineering role as observed when he participated in the NSF study. While serving in the engineering technician role, the civil engineer was also concurrently working toward his bachelor's degree in civil engineering. The combined experience of his engineering technician role, his later role as the civil engineering manager, and his civil engineering education contributed toward the requirement of having five years of experience working in engineering industry.

Last, engineers were selected based on recommendations from their supervisors as being excellent communicators and effective problem solvers. This selection criterion was used in order to ensure that the selected engineer participant had previously demonstrated effective problem-solving strategies that led to positive outcomes for the company at which they worked.

3.9.2 Dissertation Study Case Selection

Four practicing engineers who participated in the NSF-funded study were selected as cases for analysis for this dissertation study. Each of the four selected engineers provided informed consent (see APPENDIX C) to participate in this dissertation study and represented a bounded case. Creswell (2013) stated that case studies typically consist of "no more than four or five cases" (p. 101) to preserve detail and thoroughness of the analysis of each case. Yin (2018) suggested that the choice in the number of cases for a multicase study should depend on the researcher's "desired number of case replications – both literal and theoretical" (p. 94). Yin further emphasized this point by stating,

> "For example, you may want to settle for two or three literal replications when your theory is straightforward and the issue at hand does not demand an excessive

> degree of certainty. However, if your theory is subtle or if you want a higher degree of certainty, you may press for five, six, or more replications" (p. 94).

Additionally, Stake (2006) stated,

> "The benefits of multicase study will be limited if fewer than, say, 4 cases are chosen, or more than 10. Two or three cases do not show enough of the interactivity between programs and their situations, whereas 15 or 30 cases provide more uniqueness of interactivity than the research team and readers can come to understand" (p. 22).

Based on these ideas, this dissertation study contextualized and analyzed the features of four distinct engineer cases. Each selected case represents an engineer working at a different company, in a different discipline, and in a different job role than the others. These engineers were considered as the "oldtimers" (Lave, 1991, p. 72) who were established members of the engineering discipline community of practice. When the researcher initially reached out four engineers for participation (in accordance with the IRB protocol), one of the engineers did not respond (mechanical). The researcher then contacted the second mechanical engineer that participated in the NSF study and also received no response. The researcher then requested participation from the biological engineer and received her consent to participate. Overall, based on the availability of the engineers and the responses received to the requests for participation, one electrical, one biological, one chemical, and one civil engineer were selected for participation in this dissertation study.

Stake (2006) noted that one of the criteria for selecting cases for a multicase study was to select cases that "provide diversity across contexts" (p. 23). The four cases selected for this study provide diversity in the context of the engineers' discipline and work environments, job roles, and overall company roles. The purposeful selection of the four engineer participants based on these criteria ensured that diverse engineering contexts were represented. Additionally, by selecting one engineer from of the four disciplines, the diversity of the case contexts was further improved. The perspectives of the purposefully selected engineers allowed for comparisons to be made against one another to identify similarities and differences that were present due to the engineers' diverse contexts. A summary of the four engineer participants chosen for this dissertation study is presented in Table 3-3.

Table 3-3

Summary of the Four Engineer Cases.

Engineering discipline	**Definition of discipline**	**Company**	**Title and role**	**Years in industry**	**Gender**	**Race/Ethnicity**
Electrical	An engineer who designs, develops, tests, and inspects electronic equipment, such as motors, automobiles, or communication systems (Bureau of Labor Statistics, 2021d)	• Small (< 200 employees) • Startup • Privately held • Designed control systems and software for applications in various industries	Electrical engineer in hardware design and testing	9	Male	White
Biological	An engineer who integrates their engineering knowledge with biological science training to design equipment and devices for improving human health (Bureau of Labor Statistics, 2021a)	• Medium (> 500 employees) • International • Employee-owned • Worked with products for human consumption	Biological process engineer in process and application	6	Female	White

Chemical	An engineer who uses principles from chemistry and other sciences, such as physics, math, and biology, to design and develop processes to manufacture products such as food, drugs, and chemicals (Bureau of Labor Statistics, 2021b)	• Large (< 5,000 employees) • International • Public company • Produced products for human consumption	Operations manager in continuous improveme nt and efficiency	20	Female	White
Civil	An engineer who analyzes, designs, and prepares systems for public and private infrastructure, such as bridges, roads, tunnels, and buildings (Bureau of Labor Statistics, 2021c)	• Small (< 20 employees in engineering department) • Municipality • Not for profit	Assistant engineer in project manageme nt and engineering oversight	3	Male	White

These four engineers were selected to provide diversity in each of the cases as recommended by Stake (2006) to allow for robust cross case analysis with transferable findings. Each engineer represents a diverse case that is situated within their own unique context and provided insights into how habits of mind were represented in the work of each engineer's context. The engineer cases are diverse in terms of the discipline of engineering in which the work; the size of their company in terms of number of employees; whether or not their company was for profit or not for profit; the local or international presence of their company; the engineers' individual roles and job focus within their company; whether or not the engineers were licensed professional engineers; the engineers' time since graduation; and the engineers' self-identified gender. By providing thick descriptions about each of these cases that are diverse in context, findings from this study will more easily be able to be transferred to other situations or contexts (Creswell, 2013).

Different contexts are also significant to this case study due to the situated learning theoretical framework. In this study, each engineering discipline itself is considered to be a community of practice. Lave and Wenger (1991) stated that activities, understandings, and skills are developed and fostered within communities of practice. Furthermore, they posited that the relationships between these skills, activities, and understandings are part of a "broader [system] of relations in which they have meaning" (p. 53). In accordance with situated learning theory, the context in which each engineer case is defined will have its own community of practice comprised of shared activities, ways of knowing, and skills that are central to each particular community. Therefore, the habits of mind that are represented in the work of each engineer within their defined case are shaped by their unique contexts and disciplines.

For example, in their interviews with practicing engineers validating their Engineering Habits of Mind (EHoM) conceptualizations, Lucas and Hanson (2016) identified that certain habits of mind may be more relevant for engineers working in a particular stage in their careers. Therefore, to ensure that a broad representation of habits of mind were identified, engineer participants that worked at different levels within their company and with different levels of experience within their field were selected for this study. This supported the analysis of how habits of mind are represented within different communities of practice in engineering and how these habits may be similar or different to those used by engineers in a different community or context. The diverse contexts that are represented by each of the selected engineer participants also enhance the transferability of the study, increasing the likelihood that the results can be transferred to other, similar contexts.

The following sections (3.9.2.1 through 3.9.2.4) will provide overview descriptions of each of the four engineer cases selected for this dissertation study (i.e., one electrical, biological, chemical, and civil engineer). Descriptions are provided about the context of the company they worked for, their work focus and primary workplace roles, and the nature of the work they performed.

3.9.2.1 Electrical Engineer

The electrical engineer participant selected for this study worked at a privately held startup company in the United States. This company was small, consisting of less than 200 employees. His company produced electrical control systems and software that were used by clients in a variety of types of industries.

The electrical engineer's role at the company was to design and test hardware. His formal title as written on his resume was "Electrical engineer." When asked what his specialty at the company was, he described that he "develop[s] electronic systems to function together," and that his role tends to "sit in-between…trying to bridge the gap between what is theoretically possible and what is feasibly accomplishable." He described how he also works with compliance, electromagnetics, and designing prototypes of different electrical systems in order to generate designs that are "practical, functional, and producible."

At the workplace, this engineer often worked hands-on in an engineering-shop environment with electrical equipment, tools, and machinery in order to accomplish different tasks. For example, during several of the observation sessions, he was preparing a test bench setup for a motor system and had to reference wiring diagrams and schematics, determine how to properly set up the wiring harness, and adjust the testing parameters on the associated computer software.

3.9.2.2 Biological Engineer

The biological engineer selected for this study specialized in process and applications at her company. The employee-owned, international company that she worked for was of a medium size, consisting of more than 500 employees across locations globally. Her company worked on products that had an end-use of human consumption.

The biological engineer's formal job title was "Biological process engineer." She described her work on a daily basis as consisting of "a lot of fieldwork, a lot of data analysis and then developing the case studies," as well as being part of the process to "set up all the tools we need to design [the product], to estimate it, like we do with our more established products." Her role at his company was primarily in process analysis and evaluation of biological products. She described how she provided support on the "design and estimation and proposals" for different groups at the company working on products that made use of biological processes. Additionally, she described how she participated in the marketing component of the company's products, such as helping to develop "the sales materials and design programs."

The typical work environment for this engineer was in an office setting with other engineers close by in individual cubicles. She typically worked with Excel calculation programs on her computer, Word documents, or typed reports to obtain or evaluate information related to the problem she was trying to solve.

3.9.2.3 Chemical Engineer

The chemical engineer selected for this study worked at a manufacturing plant of a large (approximately 5,000 employees), publicly-traded company in the United States. The company, which is international in scope, has many site locations throughout the United States. Her company produced products that were intended for human consumption.

The chemical engineer's formal job title was "Operations manager." She described her daily work as being "responsible for the safety and well-being of 120 employees" along with the responsibility of ensuring they met the proper production output and that the quality of the product adhered to the appropriate standards. Her role at the company was to oversee the operations of both people and processes in accordance with industry-accepted continuous improvement methodologies. She described her specialty at the company as being a “social engineer,” where she oversees the “convergence of people and process” and “not so much the technical stuff.”

This engineer worked primarily in an office environment where she frequently would consult other colleagues in the office or on the manufacturing floor. The office environment was a clean space, where all employees and visitors were required to wear shoe coverings and coats, and employees that were on the manufacturing floor were required to wear safety hats and follow proper hygiene precautions. She also frequently visit the production floor to monitor the processes that she implemented and consult with operators and technicians about the status of the processes and production.

3.9.2.4 Civil Engineer

The civil engineer selected for this study worked at a small, not-for-profit, municipal government engineering organization in a city in the United States. The engineering department in this municipality consisted of less than 20 employees.

The civil engineer specialized in project management and oversight of engineering operations related to the city. His formal title was “Assistant engineer.” He described his daily work as primarily consisting of “communication,” and that “it’s really not a whole lot of modeling or quantification or calculation. It’s purely communication in one form or another.” During the observations, he would frequently send emails, make or respond to phone calls, or review engineering reports that were sent to him. He also frequently used computer-based applications where he analyzed satellite maps, reviewed geographic information about a site location, or reviewed map and building plans for construction or demolition. He described how another part of his duties was to draft the standards and specifications for a project before the team “put it out to bid.” He would then review any projects for “compliance to our city standards and specifications” by referencing the appropriate industry standards.

The civil engineer primarily worked in a private office environment with other private offices and cubicles nearby. Colleagues would either drop into his office to discuss an issue in person or would call him on his office phone to discuss at a distance. He also described how he would occasionally work outside at a field site, taking photographs, measurements, or a survey of the geographic features of the site.

3.9.3 Transferability

Due to the common regional location of the worksites of all of the participants, the results of this study are not transferable to all practicing engineers in the United States or other countries globally. However, this study aims to promote transferability in the sense that the findings may be able to be adapted and applied to new situations that have a degree of similarity in their contexts (Lincoln & Guba, 1985; Patton, 2002). Providing thick descriptions about the contexts in which the data this study were collected can enhance the likelihood that the findings will be transferable to other contexts (Creswell, 2013). Insights into the representations of habits of mind of the practicing engineers that participated in this study may be transferable to engineers at other companies, working in other regions of the country, or in different disciplines, provided that there is adequate detail provided about the other engineering contexts to make judgements about their degree of similarity.

3.10 Methods

3.10.1 Data Collection

Prior to beginning this dissertation study, the Utah State University Institutional Review Board (IRB) approved the research protocol to ensure the ethical treatment of the human participants that participated in this research. The IRB-approved letter of informed consent for this study is shown in APPENDIX C. This IRB protocol allowed for the data that were collected as part of the NSF-funded study to be used for secondary analysis during this dissertation study. This protocol also acknowledged the engineers' participation in a one-time member check session to confirm or supplement the researcher's findings from analysis.

Three types of data collected during this study (i.e., primary data) and four types of data collected as part of the NSF-funded research project (i.e., secondary data) were used for analysis and interpretation in this study. The primary data sources included information from company websites, reflective memos written by the researcher, and notes from the member checking sessions. The secondary data sources included field notes from the on-site observations at each engineer's workplace, interview transcripts, think-aloud transcripts, and engineer participant resumes. Table 3-4 outlines these primary and secondary data sources.

Table 3-4

Outline of Primary and Secondary Source Data Used in this Study.

Primary	Secondary
Company websites	Field notes from observations
Reflective memos	Interview transcripts
Notes from member-checks	Think aloud transcripts
	Resumes

As shown in Table 3-4, a variety of types of data sources were included in this dissertation study, including field notes, interview and think-aloud transcripts, and artifacts. Yin (2018) outlined six data sources that are commonly used in case study research, including interviews, direct observations, participant observations, physical artifacts, archival records, and documentation. Yin (2018) emphasized that all of these potential data sources are complementary to one another and advocated for incorporating "as many sources as possible" (p. 156) when collecting data for a case study. Creswell (2013) echoed this notion, suggesting that data collection for case studies incorporate multiple sources including interviews, observations, documents, and artifacts. Thus, using the multiple sources of data that were obtained from observations, interviews, think-aloud sessions, and artifacts allowed the researcher to develop an in-depth understanding of how practicing engineers used habits of mind in a real-world context.

3.10.1.1 Primary Data Sources

3.8.1.1.1 Company Websites. Two types of artifacts, one primary data source and one secondary data source, were included in this study to provide information about each engineer's personal work history as well as to gain insight into the context and culture of each engineer's workplace (Given, 2008). The primary source artifact that was used for this study included the company websites for each engineer participant's workplace. Details about the nature of each engineer's company were obtained from these websites, including the relative size of the company in terms of the number of employees, whether the company was public or privately held, and if the company operated primarily locally or internationally. These details provided contextual insights to understand the goals and culture of each company and how the work of each engineer participant was situated within those contexts.

3.8.1.1.2 Reflective Memos. Reflective memos were written by the researcher to document an account of each engineer participant's work environment and their daily work life. This reflective memo helped build context in each of the engineer cases to strengthen the case descriptions, thus providing a stronger opportunity for transferability of the findings. Memos help the researcher write about and think more deeply about the situations and participants that are under investigation in a research study (Saldaña, 2016). Memos augment the ideas generated through qualitative analysis and provide opportunities for the research to "reflect and expound" (Saldaña, 2016, p. 45) upon the data being analyzed. By writing a reflective memo describing the environment and day-to-day processes occurring at each engineer's workplace, a more detailed understanding of each unique engineer case was built, thus enhancing the findings about habits of mind from each case.

3.8.1.1.3 Notes From Member-Checking Sessions. The researcher took detailed notes during each of the member-checking sessions with the four engineer participants. During member check sessions, each engineer was provided with a summary of the findings related to their data specifically and information about the overall themes that were generated through the second cycle of coding. The researcher prompted the engineers for their perspectives on their top three most common habits of mind; the habits of mind labels and definitions; the grouping of the codes into larger habits of mind thematic categories; and the definitions of the habits of mind thematic categories. A summary of the general questions asked during the member-checking sessions is presented in APPENDIX B. The notes taken by the researcher during the member-check sessions captured the engineers' perspectives about these findings from the analysis process. The engineers' insights about the findings were written into these notes and were used as confirmation of the researcher's analysis or provided alternative ways of conceptualizing or making meaning from the findings.

3.10.1.2 Secondary Data Sources

Four data sources that were collected as part of the NSF study were used for this dissertation study. These data sources were obtained by the dissertation researcher as part of her duties as the graduate research assistant for the NSF study. These duties included conducting on-site observation sessions at each engineer's workplace during their typical work hours; conducting semi-structured interviews with each engineer participant; and conducting retrospective think-aloud protocol sessions with each engineer participant. The four data sources that resulted from these data collection methods included field notes from the observations, transcripts from the semi-structured interview session, transcripts from the think-aloud protocol sessions, and engineer resumes that were provided to the research team by each engineer participant.

3.8.1.2.1 Observations. Observations were held at each engineer's workplace during their work hours. Observations were two hours long and were held twice per month over the course of six months for a total of 12 observations with each engineer. The researcher acted as an *observer as participant* in which she acted primarily as an observer by watching and taking field notes at a short distance from the engineer (Creswell, 2013; Glesne, 2010). Observations of each engineer at their workplace over the six-month period will enhance the quality of the case study by providing an in-depth understanding of the engineers' work environments and their job functions (Creswell, 2013). During each observation at the engineers' workplaces, the researcher kept written field notes about the activities the engineers engaged in, the documents they read and/or wrote, and the conversations the engineers had with colleagues. By understanding the particular activities the engineers participated in during the observations, the researcher gained insight into each engineer's job role, the types of work they produced or evaluated, and an understanding of the contextual environment of the engineers' workplaces.

3.8.1.2.2 Semi-Structured Interviews. Semi-structured interview sessions were up to two hours long and were held once per month over the course of six months for a total of six interviews with each engineer. Interview protocols (developed by the NSF project Principal Investigator) were informed by the information captured during the on-site observation sessions as part of the NSF-funded project. The semi-structured interview format allowed for the interviewer to follow a specific set of interview questions while allowing for additional topics of conversation or participant insights to emerge as appropriate during the interview (Myers & Newman, 2007; Rubin & Rubin, 2012). Interview questions aimed to uncover the reading, writing, and evaluative strategies the engineers used while engaged with the activities that the researcher observed during the observation sessions. A sample interview protocol from the NSF study is presented in APPENDIX A.

3.8.1.2.3 Think-Aloud Protocols. Retrospective think-aloud protocol sessions were held once per month as part of the interview session over the course of six months for a total of six think-aloud sessions with each engineer. Think-aloud sessions are where participants are asked to verbalize their thoughts as they participate in a problem-solving activity (Koro-Ljungberg et al., 2013). Two types of think-aloud protocols include concurrent and retrospective protocols. Concurrent protocols involve a participant simultaneously working on a task and verbalizing their thought process as they complete the task (Van den Haak & De Jong, 2003). In contrast, retrospective protocols are where participants retroactively recount their thought processes that they employed when completing a task in the past while being prompted by the task they had engaged with (Van den Haak & De Jong, 2003).

The NSF-funded study used retrospective think-aloud protocols to elicit the thought processes that the engineers employed while solving a problem at the workplace. The topic for each think-aloud protocol session was informed by the information captured during the on-site observation sessions for the NSF-funded project. Think-aloud protocols were written by the Principal Investigator of the NSF-funded project. During the think-aloud sessions, the engineers were prompted to recount their thought processes as they engaged with a particular task that was observed during the observation session. Engineers were asked questions such as, “Would you mind providing an overall context of this document?” and “Would you mind sharing your thought processes as you created this text?" and were prompted for follow-up questions based on their responses to the initial question. Additional think-aloud protocol prompts are presented in APPENDIX A.

3.8.1.2.4 Resumes. The second artifact that was used for this study, obtained from the original data set from the NSF study, included resumes from the engineer participants that they provided to the research team. Engineer resumes were used to provide insight into each engineer's work history as well as their current company position. The resumes highlighted the engineers' particular job roles and the tasks that they completed to fulfill those job roles.

3.10.2 Appropriateness of Secondary Data for this Study

The secondary data for this study were collected by the dissertation researcher as part of a previously funded NSF project with different research questions and theoretical framework. These data were appropriate to be reused for this study to provide insights into the habits of mind of the engineers. In the NSF-funded study, the interview and think aloud transcripts were coded for the types of cognitive frameworks that the engineers used when solving workplace problems. During this analysis, the research team found evidence of the engineers making use of the concepts of values and attitudes when answering interview questions and describing their solution processes during the think-aloud sessions. This suggested that the engineers were using elements of habits of mind (as defined by Project 2061 (Rutherford & Ahlgren, 1990)) when solving problems and evaluating the solutions.

Additionally, the field notes showed evidence of the engineers making use of skills when solving workplace problems, such as using computation and estimation skills, communicating ideas with stakeholders and other engineers, and judging credibility of proposed problem solutions. These types of skills are also included in the Project 2061 habits of mind framework. This evidence further suggested that elements of habits of mind were present in the engineers' thought processes as they engaged with their work tasks and can be explored further using the research questions and methodology outlined for this study.

3.11 Data Analysis

Secondary data (i.e., on-site observational field notes and transcripts from interviews and think-aloud sessions) were analyzed using qualitative coding procedures. Coding methods including initial, focused, and axial coding procedures were used (Saldaña, 2016). A codebook containing identified codes, definitions, and representative excerpts was developed during the first cycle of coding. The codebook was revised and updated as the researcher moved through the first and second cycles of coding. The first cycle of coding involved initial coding procedures and the second cycle of coding involved focused and axial coding procedures. The modified constant comparative method as described by Charmaz (2000, 2016) was then used to identify similarities and differences in how habits of mind were represented in the work of each engineer participant in the context of their job role, function, and discipline.

The constant comparative method has been used in studies based on traditional grounded theory methodology which employ a positivist or objectivist paradigm (Charmaz, 2000; Corbin & Strauss, 2015). However, Charmaz (2000, 2016) argued how traditional grounded theory methods (such as the constant comparative method) could be modified to allow for a constructivist (i.e., interpretivist) paradigm that accounts for multiple realities experienced by the participants and the construction of knowledge between the researcher and the participants. For this study, the modified constant comparative method was used to preserve the interpretive nature of the study while allowing for similarities and differences in the representation of habits of mind both within and across the cases to be identified.

The combination of the analysis from the retrospective think-aloud protocols, the interviews, and the field notes that were taken in real time as the engineers worked provided a deep, holistic analysis of how the engineers used habits of mind over time during their participation in the study. Furthermore, collecting and analyzing data that occurred over time aided in establishing credibility in the research study through prolonged engagement, i.e., extended time in the field with the participants (Creswell, 2013).

3.11.1 First Cycle Coding

To analyze the observational field notes and the transcripts from the interview/think-aloud protocol sessions, first and second cycle coding procedures were used. During the first cycle of coding, initial coding procedures were used (Saldaña, 2016). This phase of coding was open-ended and exploratory, allowing for initial concepts and ideas to emerge from the data (Corbin & Strauss, 2015; Saldaña, 2016). In accordance with the Project 2061 habits of mind conceptual framework (Rutherford & Ahlgren, 1990) and the Engineering Habits of Mind (EHoM) framework (Lucas & Hanson, 2016), the researcher used the predefined categories and components of the habits of mind as shown in Table 3-1 and Table 3-2 as a priori codes (Saldaña, 2016) to guide the coding process while allowing for new codes and descriptions to be identified.

Together, the processes of initial and a priori coding allowed for the analysis to be emergent and grounded in the data while ensuring alignment with the ideas presented in the habits of mind conceptual frameworks.

3.11.2 Second Cycle Coding

During the second cycle of coding, both focused and axial coding procedures were used to analyze the field notes and the transcripts from the interview/think-aloud protocol sessions. The goal of the second cycle coding process was to reorganize and arrange the codes generated during the first cycle of coding into larger categories or themes and develop an broad understanding of how the categories were related (Saldaña, 2016). Focused coding was first conducted to organize the initial codes into broader categories that characterized them (Saldaña, 2016). Axial coding was then conducted to make connections between the categories and identify how they were related (Charmaz, 2014).

3.11.3 Peer Debrief

Peer debriefing sessions were conducted between the researcher and a second coder was established to ensure consistency and accuracy in the codes generated and applied to the data (Saldaña, 2016). The second coder was a peer with a background in engineering education who had experience conducting qualitative research. This coder was provided with the codebook, one interview/think-aloud transcript per engineer, and field notes from one observation per engineer. The peer coder reviewed the codes that were applied by the researcher and stated whether they agreed or disagreed with the researcher's interpretations. The researcher iteratively updated the applied codes and the codebook based on the feedback from the peer coder until 100% agreement was reached together.

3.11.4 Case Analyses

After determining an initial set of codes from first and second cycling coding, the field notes and interview/think-aloud protocol data were re-analyzed using the modified constant comparative method (Charmaz, 2000, 2016) to explore the data for similarities and differences across the cases (Corbin & Strauss, 2015). The modified constant comparative method also allowed the researcher to acknowledge the presence of multiple realities experienced by each participant and continually monitor the relationship between themselves, the data, and the developing categories and codes (Charmaz, 2000, 2016; Corbin & Strauss, 2015; R. B. Johnson & Christensen, 2017).

Stake (2006) described how each case should be "studied to gain understanding of that particular entity as it is situated" (p. 40). Accordingly, a within-case analysis was first conducted to identify how habits of mind were represented in the work of each engineer participant situated within their own specific engineering context. In addition to the codes developed through the first and second cycle of coding, information from the engineer participants' resumes and company websites were used to provide thick descriptions of the context of each of the engineer cases. Similarly, the development and writing of the reflective memo by the researcher provided further insights into the context of engineer case by providing rich, detailed descriptions about the environments in which each engineer worked. Together, these six data sources provided a detailed account of the context of each engineer case, the types of problems and daily tasks that each engineer engaged with, and firsthand recollections about the thought processes that each engineer was using as they solved problems that were authentic to their work.

After identifying insights about habits of mind from the within-case analysis, a cross-case analysis was performed to determine whether these ideas about habits of mind show replication across the cases (Yin, 2018). The cross-case analysis provides evidence on whether there is "uniformity or disparity" (Stake, 2006, p. 40) between the cases about the characterizations of the phenomenon under study. Conducting a cross-case analysis allowed for similarities and/or differences about how habits of mind were represented in the work of engineers across four disciplines to emerge and inform the overall understanding about habits of mind of practicing engineers. The individual analyses performed for each engineer case during the within-case analysis informed the cross-case analysis. Concepts identified from the analysis of the six data sources were compared and contrasted against one another for each engineer case. When conducting a cross-case analysis, Yin (2018) notes that the researcher should,

> "be prepared to think upward conceptually, rather than downward into the domain of individual variables. You decided to do case study research because you favored its holistic feature and wanted to understand phenomena in their real-world settings. The desired cross-case synthesis should strive to retain the holistic feature rather than settle for any variable-based approach" (p. 247).

The cross-case analysis thus provided an overall conceptual basis for how habits of mind were represented in the work of the four selected practicing engineers and how the representations were similar or different across four different engineering contexts. Additionally, this analysis can lead to a list of general engineering habits of mind that are common across the four engineer cases.

3.12 Research Credibility

An important aspect of conducting qualitative research is establishing the extent to which the findings are "sufficiently authentic" (Lincoln et al., 2011, p. 120) and could "be trusted" to suggest "action that can be taken on the part of the research participants to benefit themselves or their particular social contexts" (p. 120). Lincoln and Guba (1985) suggested that concepts such as credibility, transferability, dependability, and confirmability should be used to adhere to the "naturalistic epistemology" (p. 219) of qualitative inquiry and provide means for judging the quality of a qualitative study. Lincoln and Guba (1985) then proposed several techniques for promoting credibility in a naturalistic study, including: prolonged engagement; persistent observation; triangulation; peer debriefing; negative case analysis; referential adequacy; and member checking (p. 301). Guided by these suggestions, this study established credibility through prolonged engagement; persistent observation; peer debriefing; and data triangulation through using multiple sources of data.

3.12.1 Prolonged Engagement

One method of ensuring credibility in the data analysis is through prolonged engagement by spending an extended time in the field with the participants (Creswell, 2013; Lincoln & Guba, 1985). This is the process by which the researcher spends sufficiently enough time in the field to build trust with the participants, learn the culture of the environment under study, and make judgements about relevant data to include in the study (Lincoln & Guba, 1985). The data collection process for this study involved prolonged time spent in the field with each engineer participant: two-hour observations twice per month and up to two-hour interview/think-aloud sessions once per month, both over the duration of six months with each engineer. This prolonged engagement with each engineer participant allowed the researcher to understand each engineer's workplace culture, appreciate the context of each engineer in terms of their job role and function, and build trust with each participant, enhancing the credibility of any findings from the obtained data.

3.12.2 Persistent Observation

Persistent observation is the process of identifying "characteristics and elements in the situation that are most relevant to the problem or issue being pursued and focusing on them in detail" (Lincoln & Guba, 1985, p. 304). Persistent observation involves engagement of the researcher with the participants and their environment with enough frequency to allow the researcher to make judgements about salient information to include in the data collection and analysis processes (Creswell, 2013; Davis, 1995). This study utilized this strategy by accounting for the numerous instances of interactions that the researcher had with each engineer participant. Over the course of six months, the researcher observed each engineer a total of 12 times for two hours per session. Therefore, the total number of hours of observation of each engineer was 24 hours. Through these frequent observations, the researcher was able to deeply understand the context of each engineer's specific job functions and their overall work environment. This enabled the researcher to make informed judgements about the significant and relevant information to include while taking field notes during the observations.

3.12.3 Triangulation

To further enhance credibility of this qualitative study, the data were triangulated through the use of multiple data sources (Creswell, 2013; Lincoln & Guba, 1985; Miles & Huberman, 1994). Using multiple sources of data in a case study allows for the researcher to develop “converging lines of inquiry” (Yin, 2018, p. 171) that supplies in-depth, contextual insights about the phenomenon being investigated. This study considered information collected from the field notes from the on-site observations; transcripts from the interview and think-aloud sessions with each engineer; notes from the member-checking sessions that were conducted with each engineer; and information provided in the researcher’s reflective memos about each engineer case. Consulting these multiple sources aimed to provide corroborating evidence of the findings about habits of mind across the sources and strengthened the overall findings of the case study (Creswell, 2013; Lincoln & Guba, 1985; Miles & Huberman, 1994; Yin, 2018).

3.12.4 Member-Checking

Credibility in the data was further enhanced participant member-checking. Lincoln and Guba (1985) argued that member-checking “is the most crucial technique for establishing credibility” (p. 314). This is the process by which the researcher brings the data, interpretations, and conclusions back to the participants to solicit their feedback on whether the researcher’s findings are accurate representations of the phenomenon (Creswell, 2013; Lincoln & Guba, 1985). Stake (1995) emphasized that for case study research, the participants should “play a major role directing as well as acting” and should provide “critical observations or interpretations” (p. 115) of the researcher’s analysis. Thus, the findings and analyses from each engineer’s data were member checked with the respective engineer. This ensured that any interpretations about the habits of mind made by the researcher accurately reflected the participants' perceptions about the situation under consideration.

3.12.5 Peer Debriefing

Last, credibility was established through peer debriefing. Lincoln and Guba (1985) described peer debriefing as the "process of exposing oneself to a disinterested peer" to evaluate claims made by the researcher "that might otherwise remain only implicit" (p. 308) within the mind of the researcher. One way to employ peer debriefing is by having a peer provide their opinions and interpretations on the initial analysis that has been done by the researcher (Barber & Walczak, 2009; Korstjens & Moser, 2018). This process keeps the researcher "honest" (Lincoln & Guba, 1985, p. 308) and keeps them open to alternative interpretations and perspectives on the analysis of the data. For this study, peer debriefing was accomplished by having a peer familiar with qualitative research review a subset of the data (i.e., one set of field notes and one interview/think-aloud transcript for each engineer) that was coded by the researcher using the codebook. The peer's interpretation of the applied codes was then compared with those applied by the researcher. Discrepancies in the applied codes were discussed by the peer and the researcher until 100% agreement was established.

3.13 Limitations

This study is limited in several ways. First, this study uses secondary data that were initially collected under a separate research project to answer different research questions using different theoretical and conceptual frameworks. The secondary dataset consisted of field notes from observations, transcripts from semi-structured interviews, transcripts from think-aloud protocol sessions, and engineer resumes. Different results may have been obtained if the interview and think-aloud questions were targeted specifically to uncover habits of mind rather than implicitly. However, this data can still provide valuable insights into an early exploration of the habits of mind of the engineers.

For example, when the data were previously coded for cognitive frameworks that the engineers used when solving workplace problems during the NSF-funded study, the research team found evidence of the engineers making use of *values* and *attitudes* in their solution approaches. These findings suggest that the engineers were using elements of habits of mind (as defined by Project 2061 (Rutherford & Ahlgren, 1990)) when solving problems and evaluating the solutions. The data also showed evidence of the engineers making use of *skills* when solving workplace problems, such as using computation and estimation skills, communicating ideas with stakeholders and other engineers, and judging credibility of proposed problem solutions. These types of skills are also included in the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990). This evidence further suggests that habits of mind played a role in guiding the engineers' thought processes as they worked and can be explored further in this study using the proposed methodology. Furthermore, the identified habits of mind were reflective of the habits that have been previously identified in the engineering education literature (K.

Johnson et al., 2019; Pitterson et al., 2018; Yellamraju et al., 2019). These ideas provide evidence that the secondary data were appropriate to answer the research questions proposed for this dissertation study.

This study is also limited in that it explored the habits of mind of four engineers. Additional insights into habits of mind may have been obtained if a larger population of engineers was investigated. However, considering a small population of engineers for this study provided the opportunity for a rich, detailed investigation of each participant's context. The case study approach in particular allowed for deep insights to be obtained from the analysis of each of the four engineer cases that accounted for their distinct engineering disciplines, diverse workplace environments, and specific job roles and functions. These detailed insights were uniquely obtained from the small population of engineer cases that were explored in this study.

Additionally, this study is limited in that it was conducted in one region of the western United States that contains a dominant race and religious culture. Therefore, the habits of mind that were observed within the work of the engineers from this region of the United States may or may not reflect the habits of mind exhibited by engineers who are located in other regions of the United States or in other countries. The all White and regionally specific cultural and racial/ethnic makeup of the four engineer participants may have limited the behaviors, values, and ways of knowing and thinking that were observed in the work of the four engineer participants. Therefore, the results of this study may have missed behaviors and values that should be included within a model of engineering habits of mind or may not be transferable to all practicing engineers. However, the findings are transferable to other engineering contexts that are similar to those of this study (Lincoln & Guba, 1985). Findings also support the purpose of this dissertation study in developing an initial, exploratory understanding of how habits of mind are represented in the work of practicing engineers. These findings can be used to inform future research that can expand upon these findings and conduct similar research with more diverse participants.

Last, this study is limited by exploring the work of participants from only four disciplines of engineering. This study explored the habits of mind of engineers from electrical, civil, biological, and chemical engineering. The habits of mind that are represented in the work of these engineers may differ from those used by engineers in other disciplines of engineering that were not considered in this study. However, the disciplines of engineering chosen from this study are among the most common disciplines of engineering based on undergraduate university enrollment and are in demand within the engineering workforce (Bureau of Labor Statistics, 2016; National Center for Education Statistics, 2013).

In addition, the engineers selected for this study represented diverse contexts that provided detailed insights into the context of their work environment and role as engineers. The engineers had varied levels of experience within their company and served different job roles and functions. Engineers working at different stages in their career or levels within their companies may use different habits of mind that are a function of these career stages. Each engineering company also had varying scopes of work, size, and geographical presence. The engineers selected for this study were purposefully chosen across these different contexts to improve the transferability of the findings to other situations.

CHAPTER 4

FINDINGS

The purpose of this study was to explore the habits of mind that were used by practicing engineers at their workplaces. This study was guided by the following research questions:

1. How are habits of mind represented in the work of practicing engineers?
2. How do habits of mind, as represented through the work of practicing engineers, compare and contrast across engineer case contexts?

To answer these research questions, qualitative data including information from the engineers' company websites, the researcher's reflective memos, field notes from on-site observations, transcriptions from interview and think-aloud sessions with each engineer, notes from member-checking sessions, and the engineers' resumes were analyzed. The analysis of the field notes and interview transcriptions help to answer Research Question 1. The information from the company websites, the researcher's reflective memos, notes from the member-checking sessions, and the engineers' resumes were used to provide context for each of the four engineer cases and primarily help to answer Research Question 2.

During the first cycle of coding, the field notes and interview/think-aloud transcripts were analyzed using initial coding procedures to allow for codes to emerge from the data in addition to a priori conceptualizations of habits of mind as presented in Table 3-1 and Table 3-2. The researcher segmented the field notes from the observations into paragraphs that were separated each time the engineer performed a new task. Each segment was then coded analyzed to determine if any of the a priori codes should be applied. If there was an idea present in the segment that was not captured by the a priori codes but was related to habits of mind, the researcher created an initial code that represented the new idea and added the new code to the codebook. If the segment did not contain any representations of habits of mind, the segmented was not coded. The interview and think aloud transcripts were not segmented. The researcher read the transcripts as transcribed and coded the engineers' responses if there were representations of habits of mind within them. The researcher coded paragraphs or sentences for different habits of mind depending on the response to ensure the proper habits of mind were captured within each idea the engineers described in their responses. The results from this first cycle of coding, including identified codes, their definitions, and the number of excerpts that were coded for each code are presented in Table 4-1.

Table 4-1

Results from the First Cycle of Coding.

Code	Coding cycle	Definition	Number of excerpts
Adapting	A priori[1]	Testing, analyzing, reflecting, re-thinking, changing (physically and mentally)	437
Attitudes	A priori[2]	Having a positive disposition toward learning science, mathematics, and engineering	46
Creative problem-solving	A priori[1]	Applying techniques from other traditions, generating ideas and solutions with others, generous but rigorous critiquing, seeing engineering as a "team sport"	1530
Improving	A priori[1]	Relentlessly trying to make things better by experimenting, designing, sketching, guessing, conjecturing, thought-	322

		experimenting, prototyping	
Managing impulsivity	Initial[3]	Thinking before acting; remaining calm, thoughtful, and deliberative	9
Problem finding	A priori[1]	Clarifying needs, checking existing solutions, investigating contexts, verifying information	2959
Visualizing	A priori[1]	Moving from abstract to concrete, manipulating materials, mentally rehearsing physical space and practical design solutions	330

Systems thinking	A priori[1]	Seeing whole, systems and parts, and how they connect, pattern-sniffing, recognizing interdependencies, synthesizing	1313
Skills	A priori[2]	Applying one's knowledge to problem-solving	2441
Communication	A priori[2]	Transferring ideas clearly and to read and listen with understanding	1823
Computation	A priori[2]	Using calculation and estimation skills in meaningful contexts to solve problems	201
Critical response	A priori[2]	Reading and listening to arguments (proposed by self or others) critically and making judgments about what is credible	582

Manipulation and observation	A priori[2]	Using and handling physical manipulatives, making observations, and handling information	288
Values	A priori[2]	Making decisions about concepts relevant to science and engineering, reinforcing general societal values, and thinking critically about scientific solutions	1467
Acknowledgement	Initial[3]	Realizing and recognizing the work, effort, contributions, accomplishments, and ideas of others	125
Curiosity	A priori[2]	Asking questions, seeking answers, evaluating the correctness of the answers	722

Engineering judgement	Initial[3]	Making decisions about engineering-related concepts. Using expertise as an engineer to make decisions based on intuition rather than standards or formal rules	118
Transparency	Initial[3]	Ensuring clearness/clarity, making an honest and fair decision, being upfront about information	90
Informed skepticism	A priori[2]	Questioning new ideas, appreciating the verification and refutal process of new ideas, and maintaining a personal balance between openness and skepticism	524
Openness to new ideas	A priori[2]	Considering ideas that are different from one's own or challenge one's beliefs	210

Safety	Initial[3]	Taking actions or making decisions to ensure the safety of employees, the public, or society in general	120

[1] Indicates a priori codes that were included from the Engineering Habits of Mind (EHoM) framework (Lucas & Hanson, 2016).

[2] Indicates a priori codes that were included from the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990).

[3] Indicates initial codes developed by the dissertation researcher.

During the second cycle of coding, focused coding procedures were used to group the initial and a priori codes into categories (Saldaña, 2016). The researcher observed during the analysis process that many of the a priori and initial codes could be conceptualized as either a *Value, Attitude,* or *Skill.* Accordingly, during focused coding, the researcher grouped the initial and a priori codes into the categories of *Values*, *Attitudes*, and *Skills*. The results from this cycle of coding, including the codes and the count of the number of excerpts associated with each code, are presented in Table 4-2.

Table 4-2

Focused Codes from the Second Cycle of Coding.

Code	**Definition**	**Number of excerpts**
Attitudes	Having a positive disposition toward learning science, mathematics, and engineering	805
Adapting	Testing, analyzing, reflecting, re-thinking, changing (physically and mentally)	437
Improving	Relentlessly trying to make things better by experimenting, designing, sketching, guessing, conjecturing, thought-experimenting, prototyping	322
Skills	Applying one's knowledge to problem-solving	9026
Communication	Transferring ideas clearly and to read and listen with understanding	1823
Computation	Using calculation and estimation skills in meaningful contexts to solve problems	201
Creative problem-solving	Applying techniques from other traditions, generating ideas and solutions with others, generous but rigorous critiquing, seeing engineering as a "team sport"	1530

Critical response	Reading and listening to arguments (proposed by self or others) critically and making judgments about what is credible	582
Manipulation and observation	Using and handling physical manipulatives, making observations, and handling information	288
Problem finding	Clarifying needs, checking existing solutions, investigating contexts, verifying information	2959
Systems thinking	Seeing whole, systems and parts, and how they connect, pattern-sniffing, recognizing interdependencies, synthesizing	1313
Visualizing	Moving from abstract to concrete, manipulating materials, mentally rehearsing physical space and practical design solutions	330
Values	Making decisions about concepts relevant to science and engineering, reinforcing general societal values, and thinking critically about scientific solutions	3385
Acknowledgement	Realizing and recognizing the work, effort, contributions, accomplishments, and ideas of others	125
Curiosity	Asking questions, seeking answers, evaluating the correctness of the answers	722

Engineering judgement	Making decisions about engineering-related concepts. Using expertise as an engineer to make decisions based on intuition rather than standards or formal rules	118
Transparency	Ensuring clearness/clarity, making an honest and fair decision, being upfront about information	90
Informed skepticism	Remaining skeptical of new ideas, appreciating the verification and refutal process of new ideas, and maintaining a personal balance between openness and skepticism	524
Managing impulsivity	Thinking before acting; remaining calm, thoughtful, and deliberative	9
Openness to new ideas	Considering ideas that are different from one's own or challenge one's beliefs	210
Safety	Taking actions or making decisions to ensure the safety of employees, the public, or society in general	120

Last, the researcher used axial coding to identify the relationships between the categories. The focused codes of *Values* and *Skills* were removed and the underlying codes were subsumed into thematic categories with other codes that had similar core ideas. These thematic categories represent the habits of mind that were employed by the engineer participants: *Problem-focused, Self-reflective, Interpersonal, Mindful of the bigger picture*, and *Technically adept.* These habits of mind represented the central ideas that were present in the previously identified codes and themes. Figure 4-1 presents an overview of these habits of mind with the corresponding initial and focused codes that were grouped into them.

The rationale for the grouping of initial and focused codes into these larger themes is discussed in detail in Sections 4.1.1 through 4.1.5. A discussion of each these habits of mind, including their definitions and examples from the field notes and interview/think-aloud transcripts are also presented in these sections. The results from this cycle of coding are presented in Table 4-3. This table defines each of the five habits of mind, demonstrates which codes and themes from the initial and focused coding procedures were grouped into each of the five habits of mind, and presents a count of the number of excerpts that were coded within each of the five habits of mind. The count of the instances of these habits was obtained by summing the counts of the individual codes that comprised each habit.

Figure 4-1

Overview of the Five Habits of Mind That Were Identified During Data Analysis.

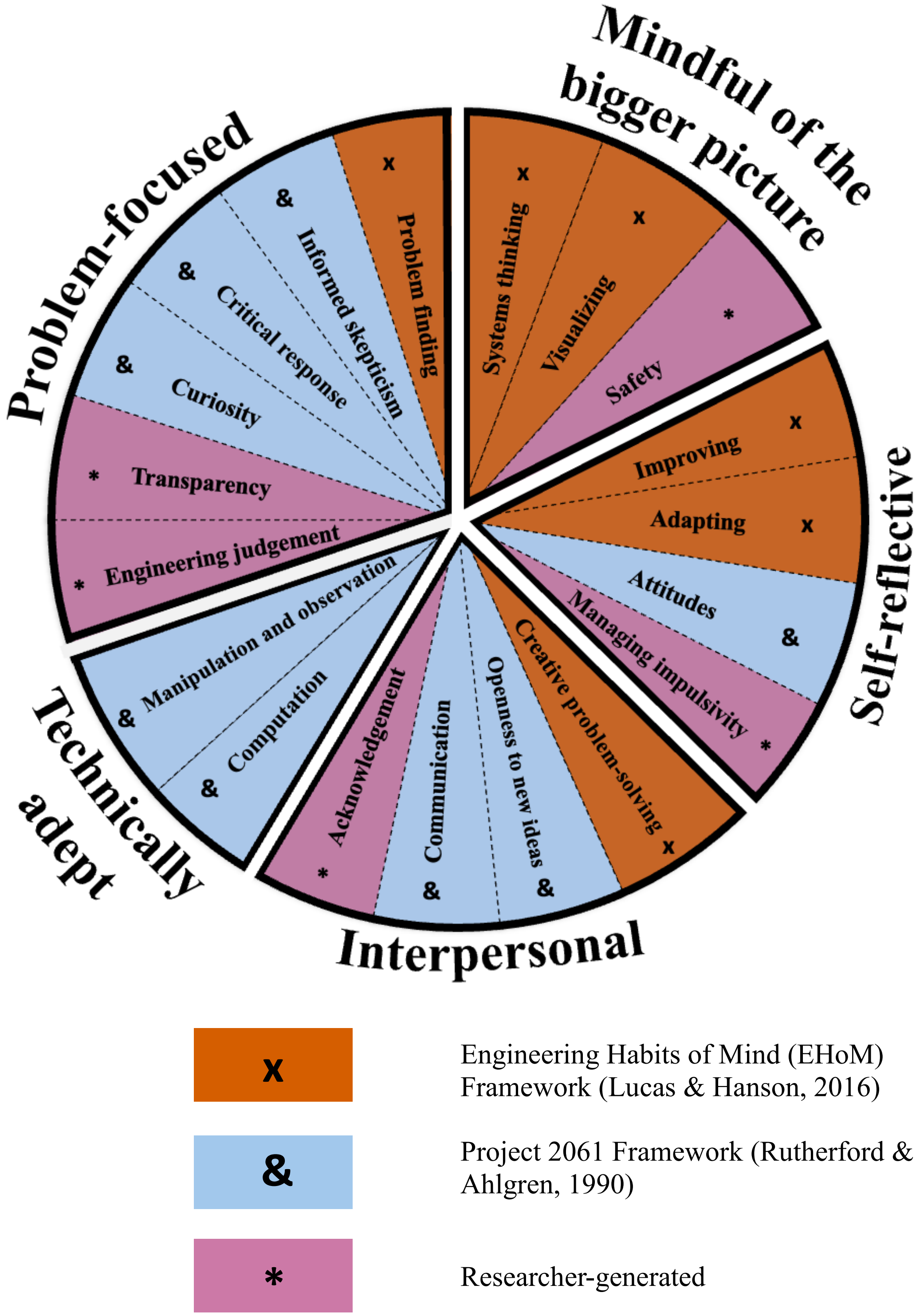


Table 4-3

Axial Codes from the Second Cycle of Coding.

Code	Definition	Number of excerpts
Problem-focused	How the engineers engage in the problem solving process, e.g., through investigating, evaluating, or generating solutions to problems	4995
Critical response	Reading and listening to arguments (proposed by self or others) critically and making judgments about what is credible	582
Curiosity	Asking questions, seeking answers, evaluating the correctness of the answers	722
Engineering judgement	Making decisions about engineering-related concepts. Using expertise as an engineer to make decisions based on intuition rather than standards or formal rules	118
Informed skepticism	Remaining skeptical of new ideas, appreciating the verification and refutal process of new ideas, and maintaining a personal balance between openness and skepticism	524
Problem finding	Clarifying needs, checking existing solutions, investigating contexts, verifying	2959

Transparency	Ensuring clearness/clarity, making an honest and fair decision, being upfront about information	90
Interpersonal	How the engineers communicate and work with others	3688
Acknowledgement	Realizing and recognizing the work, effort, contributions, accomplishments, and ideas of others	125
Communication	Transferring ideas clearly and to read and listen with understanding	1823
Creative problem-solving	Applying techniques from other traditions, generating ideas and solutions with others, generous but rigorous critiquing, seeing engineering as a “team sport”	1530
Openness to new ideas	Considering ideas that are different from one’s own or challenge one’s beliefs	210
Self-reflective	How the engineers reflect on their own actions, maintain personal composure, and express a positive attitude toward learning or problem solving	814
Adapting	Testing, analyzing, reflecting, re-thinking, changing (physically and mentally)	437

Attitudes	Having a positive disposition toward learning science, mathematics, and engineering	805
Improving	Relentlessly trying to make things better by experimenting, designing, sketching, guessing, conjecturing, thought-experimenting, prototyping	322
Managing impulsivity	Thinking before acting; remaining calm, thoughtful, and deliberative	9
Mindful of the bigger picture	How the engineers approach problems and solutions holistically and consider the broader impacts of their work	1763
Safety	Taking actions or making decisions to ensure the safety of employees, the public, or society in general	120
Systems thinking	Seeing whole, systems and parts, and how they connect, pattern-sniffing, recognizing interdependencies, synthesizing	1313
Visualizing	Moving from abstract to concrete, manipulating materials, mentally rehearsing physical space and practical design solutions	330
Technically adept	How the engineers use technical tools, such as physical manipulatives, testing setups, or computation tools, during their work	489

Computation	Using calculation and estimation skills in meaningful contexts to solve problems	201
Manipulation and observation	Using and handling physical manipulatives, making observations, and handling information	288

4.1 Identified Habits of Mind

4.1.1 Habit of Mind 1: Problem-Focused

One of the habits of mind identified from the analysis of the field notes and interview/think-aloud sessions was the idea of being *Problem-focused.* This habit of mind was represented in the engineers' work while they were investigating, evaluating, or generating solutions to problems that they encountered on a day-to-day basis. The codes that were grouped into this theme have a central idea relating to how the engineers engaged in this problem solving process. These codes included *Problem finding, Informed skepticism, Critical response, Curiosity, Transparency,* and *Engineering judgement.* These codes all have a central theme relating to exploring problems and solutions, making decisions about solutions, and remaining critical of information.

The *Problem-focused* habit of mind was represented in the data from all four engineer cases. Table 4-4 provides a count of the number of excerpts in which *Problem-focused* and its components were represented. This table demonstrates how this habit of mind was represented in the data from all four engineer cases, but the ways in which the individual elements within this habit that were enacted depended on the engineer context.

Table 4-4

Number of Coded Excerpts for the Problem-Focused Habit of Mind.

Habit of mind	Chemical engineer	Civil engineer	Electrical engineer	Biological engineer
	Number of excerpts			
Problem-focused	1341	907	790	1957
Critical response	181	162	25	214
Curiosity	259	115	152	196
Engineering judgement	18	84	7	9
Informed skepticism	98	76	32	318
Problem finding	780	465	574	1140
Transparency	5	5	0	80

Problem finding was an a priori code from Lucas and Hanson's (2016) Engineering Habits of Mind (EHoM) framework. This code was defined as "clarifying needs, checking existing solutions, investigating contexts, verifying" (Lucas & Hanson, 2016, p. 6). This code captured how the engineers investigated contexts of problems and began to contextualize potential solutions to them. *Curiosity* was similar to *Problem finding* in that it represented how the engineers asked questions, sought answers, and judged the correctness of answers. This was an a priori code from Project 2061's habits of mind framework (Rutherford & Ahlgren, 1990). *Curiosity* was grouped into *Problem finding* because part of the engineers' problem solving process involved their desire to be inquisitive about the nature of problems they were solving and seeking answers to the questions they posed. *Informed skepticism* was also an a priori code from the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990). This code was defined for this study as "remaining skeptical of new ideas, appreciating the verification process and refuting of new ideas, and maintaining a personal balance between openness and skepticism." This code was grouped into *Problem-focused* because it represented one way the engineers remained critical of information they were interpreting as they sought solutions to problems. Maintaining *Informed skepticism* was important to being *Problem-focused* because as the engineers contextualized problems and generated initial ideas, they needed to also remain skeptical of these ideas and maintain a critical eye toward information. This code is also related to *Critical response*, an a priori code from Project 2061's habits of mind framework (Rutherford & Ahlgren, 1990), which was defined for this study as "the ability to read and listen to arguments (proposed by self or others) critically and make judgments about what is credible." This code was central to *Problem-focused* because the engineers needed to be able to critique information and judge the credibility of the source of information they were investigating. The engineers needed to ensure they were handling and interpreting credible information before making decisions based on it or implementing it into a design solution.

Another code that comprised *Problem-focused* was *Transparency.* This was an initial code developed by the researcher during the first cycle of coding. This code was defined for this study as "ensuring clearness/clarity, making an honest and fair decision, being upfront about information." *Transparency* represented how the engineers made an effort to be clear and honest about how they solved problems, where they generated information from, and how they navigated ethical considerations related to problem solving. This code was apparent in different ways across the engineer cases, such as when they formulated problems with clients and needed to be upfront about costs and expectations of a design or when they designed computation programs to be clear about from where the program was importing data and how it was being used to make decisions. Being upfront and transparent throughout the *Problem-focused* habit of mind was important when formulating problem contexts and solutions because it ensured there were clear expectations among the engineers and their colleagues, stakeholders, or others who may have a vested interest in the solution.

Last, *Engineering judgement* was grouped into *Problem-focused* because it represented another aspect of how the engineers made decisions about solving problems. This code was an initial code developed by the researcher during the first cycle of coding. This code was defined for this study as "making decisions about engineering-related concepts; using expertise as an engineer to make decisions based on intuition rather than standards or formal rules." This code captured the ways that the engineers made decisions that were based on their knowledge and experience working as established members of the engineering discipline. These types of decisions were made based on intuition or feeling rather than data or standards regarding engineering problems. The ability to make *Engineering judgements* was uniquely characterized by the practicing engineers as they integrated their technical knowledge, engineering training, and familiarity with their job role or discipline to make informed decisions. *Engineering judgement* was grouped into *Problem-focused* because an important component of this habit of mind was how the engineers used their expertise within their discipline or role to make decisions. The engineers used this intuitive decision-making ability in conjunction with their technical expertise to make informed decisions related to problem solving.

4.1.1.1 Problem-Focused Examples from the Data

Problem-focused was a habit of mind that was represented in the data from all four individual engineer cases in different ways depending on the context of the case. For example, the chemical engineer described how when she and her team were establishing the context for an upcoming product campaign (*Problem finding*), she was asking questions out loud to the group (*Curiosity*) about whether or not an extra cleaning step was actually necessary, since it would delay getting the product out to the customer (*Informed skepticism*). She stated in an interview,

> "Essentially, what I was asking was, do we really have to have this sampling done on this upcoming campaign because it has effects, we have to do an extra step in cleaning. And there's also some impacts in customer service because you actually have to put the product on hold on quarantine until the testing comes back and you have to have ... The product basically test negative in order to release it. So,

> yeah, I was just asking in the room if that needed to happen. And our scheduler, I believe, answered a, you know, she essentially said yes."

The individual codes of *Problem finding, Curiosity,* and *Informed skepticism* in this example all contribute to the central idea of being *Problem-focused* while performing engineering work.

Another important element to the habit of *Problem-focused* was the idea of *Critical response.* This code is central to the *Problem-focused* habit because it involved the engineers maintaining a critical viewpoint on any information that they were provided and were using to make further decisions. The biological engineer described how she would remain critical of data that she was reviewing and would note where she saw "anomalies" that conflicted with what she expected to see. She stated,

> "But there were some anomalies. And that was another reason I thought maybe we had some sample valve issues, is those anomalies suggested to me that there was like some sort of delay or there was a mixing for a while of the samples. So we weren't getting really clear, even if the trends were similar. The numbers weren't. So precision was not high, but accuracy and trends seemed to be high. So we were confident that the trends were happening, we just weren't confident on the exact values."

She recognized that the trends and accuracy were as expected, but the data values themselves were not correct. The ability to maintain a sense of *Critical response* while being *Problem-focused* was critical to ensuring that an appropriate problem was identified and that decisions about how to solve it could be generated effectively.

The ability to enact *Engineering judgement* is also central to being *Problem-focused. Engineering judgement* is the ability for the engineers to use their personal judgement, previous experience, and prior knowledge about a subject in order to make a decision about an action or process in the context of engineering work. The civil engineer frequently made approvals requiring him to sign off on different documents indicating they met his standard for acceptance. During observations with him, the researcher observed him adding his approval stamp to various documents: "At the bottom of the submittal document, he adds a green stamp that says 'Approved.' He places this stamp over certain drawings and specification pages in the submittal document." When interviewed about his approval process, the civil engineer said that, "What it means is, it either meets the specification or the standard that we specified, wholly, or there may be a deficiency that I found that I felt was acceptable." This demonstrates how he was able to use *Critical response* to enact *Engineering judgement* based on his own experience and expertise to determine that the information contained in the document was acceptable for its intended purpose. He made these judgements based on his knowledge and familiarity with the engineering topic rather than relying on a set of standards to determine whether the deficiencies he was presented were acceptable or not. Both of these elements contribute to the ability to be *Problem-focused* and are central to ensuring that problems are solved effectively.

These examples highlight how the habit of *Problem-focused* is represented in the work of these four practicing engineer cases. These engineers frequently explored and investigated problem contexts and solutions. They asked questions and sought answers to problems. Depending on their role, they enacted their engineering judgement to make decisions based on their previous experiences or intuition. They remained skeptical of new ideas and appreciated the process of remaining critical about new ideas and information. The habit of being *Problem-focused* was comprised of these different elements and represent how the engineers engaged in investigating, evaluating, and generating solutions to problems they encountered at the workplace.

4.1.2 Habit of Mind 2: Interpersonal

Another major habit that was identified from the data analysis was *Interpersonal.* This habit of mind is characterized by how the engineers communicated and worked with others. This theme consisted of the codes of *Creative problem-solving*, *Communication, Acknowledgement,* and *Openness to new ideas.* These codes have a central theme relating to how the engineers interacted with others, including recognizing and remaining open to alternate perspectives, communicating clearly and effectively, and recognizing the value of solving problems as a team.

The *Interpersonal* habit of mind and the ways in which it was employed were found in the data across all four engineer cases. Table 4-5 provides a count of the number of excerpts that were coded for each of the habits of mind that comprised *Interpersonal.* This table reveals that all four engineer cases demonstrated evidence of all of the components of being *Interpersonal.* The number of excerpts differed for each individual element due to differences in how they were represented in the work of each engineer. The diverse context of each engineer case led the engineers to employ this habit of mind in different ways to accomplish different goals that depended on the context in which the engineer was working. However, the presence of the habit across all four cases suggests that the ability to be *Interpersonal* is broad enough to be represented across multiple, diverse contexts.

Table 4-5

Number of Coded Excerpts for the Interpersonal Habit of Mind.

Habit of mind	Chemical engineer	Civil engineer	Electrical engineer	Biological engineer
	Number of excerpts			
Interpersonal	1241	359	664	1424
Acknowledgement	75	16	3	31
Communication	597	196	319	711
Creative problem-solving	501	118	315	596
Openness to new ideas	68	29	27	86

The *Communication* code was present in all of the engineers' data and was one of the top three most common habits used by each engineer. *Communication* was an a priori code from the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990) and is defined in this study as "transferring ideas clearly and to read and listen with understanding." This finding suggests that being able to interact and listen to the perspectives and opinions of others is central to the work of all four engineers, regardless of their discipline or context. The code of *Acknowledgement* and *Openness to new ideas* reflect similar sentiments and contribute to the idea of being *Interpersonal*.

Creative problem solving was an a priori code from Lucas and Hanson's (2016) EHoM framework. This code was defined for this study as "applying techniques from other traditions, generating ideas and solutions with others, generous but rigorous critiquing, seeing engineering as a 'team sport'" (p. 6). This code was grouped into *Interpersonal* because it represents how the engineers worked with others to solve problems. It affirms the importance of generating knowledge as a group and that engineering work is not performed in isolation.

The *Acknowledgement* code was generated by the researcher during the first cycle of coding as an initial code. It is defined in this study as, "realizing and recognizing the work, effort, contributions, accomplishments, and ideas of others." *Acknowledgement* was grouped into the *Interpersonal* habit because it represents how the engineers recognized the importance that others' perspectives had when defining problems and conceptualizing solutions. Being able to recognize the efforts, contributions, and skillsets of others was an important behavior that the engineers practiced. They were able to recognize where their own skillsets could be augmented by the expertise and knowledge of others on their teams or within their company. Employing *Acknowledgement* allowed the engineers to remain appreciative of the perspectives held by fellow engineers or by stakeholders that used their end product or design to inform the design process and ensure the proper needs were met.

The last code captured in *Interpersonal* was *Openness to new ideas*. This code was an a priori code from the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990) and is defined in this study as "considering ideas that are different from one's own or challenge one's beliefs." *Openness to new ideas* was grouped into *Interpersonal* because it represented the engineers' ability to be welcoming to ideas that may differ from their own and provide an alternative perspective when defining problems and generating solution ideas. It was important for the engineer cases to consider a range of viewpoints when approaching problems. *Openness to new ideas* represented an ability for the engineers to be open to the idea that there could be multiple ways of solving a problem and that one person does not hold of all the answers. It was important to the engineers' ability to remain *Interpersonal* that they were open to changing their point of view and recognizing that their own beliefs were not always fully representative of the beliefs of their coworkers, colleagues, or the audiences their company served.

4.1.2.1 Interpersonal Examples from the Data

The *Interpersonal* habit of mind was represented in the data across all four engineer cases in different contexts. For example, during an interview, the electrical engineer stated the importance of,

> "…being able to admire the same in other people, admire things people can do that I'm not very good at, or I'm not good at at all, and to know and be glad that those people are there to fill that niche so that I don't have to because I really don't do it well."

This example demonstrates how he was using *Acknowledgement* in recognizing the skills and abilities of others, in turn expressing *Openness to new ideas* which would enable him to consider solutions and viewpoints that were unfamiliar to him.

The chemical engineer sought feedback and perspectives from fellow colleagues and often facilitated collaborative opportunities where everyone had the opportunity to share their ideas (*Creative problem-solving, Communication, Acknowledgement*). She also indicated that by encouraging this type of group work and idea generation, her employees would often raise concerns or ideas that were different than what she was expecting or had previously considered. She would ask, "Do you guys agree that this is probably our top two issues? You know, yes or no," and then realized that, "sometimes you'll find out, no, they don't feel that way." This example highlights the importance of the chemical engineer having an *Openness to new ideas* approach to her work. In order to maintain positive relationships with her employees, upholding the ability to remain *Interpersonal* was essential to her role.

Furthermore, the ideas represented by the *Interpersonal* habit suggest that the engineers' abilities to communicate their own ideas to a variety of audiences is also a central component to their work (*Communication*). The civil engineer described how he had to adjust his communication style or language depending on who he was speaking to:

> "The biggest focus of my day is writing an email depending on who it's to that made, it may dictate what tone I use or even expressions or terms. If I'm talking to another engineer, I might use acronyms but if I'm talking to the mayor, I will spell these acronyms out so it's more comprehensive."

This quote demonstrates how the civil engineer mediated his communication style based on the audience. He was able to enact his *Communication* abilities to make a specific choice about how he would interact with a particular person.

The biological engineer expressed similar sentiments when she described how she prepared presentations. She emphasized that "tailoring it [a presentation] to the audience, I think is really important," in order to effectively communicate her ideas to them. She stated,

> "If you're presenting to like a community board or a water board that doesn't have just engineers on it, but has, you know, the local teachers union and politicians and all the other interested parties where they're not really interested in, you know, what kind of statistical software you use to analyze something. But they just want to know, like, how will this help my community?"

This quote shows how the biological engineer was able to mediate her *Communication* abilities when discussing details with various audiences. She emphasized the importance of this ability when trying to communicate to non-technical audiences about the relevance and impact of her company's work.

These examples from the four engineers demonstrate how the *Interpersonal* habit of mind and its underlying elements played an important role in how the engineers interacted with, presented information to, and generated ideas with colleagues, stakeholders, or other parties.

In summary, the ability to be *Interpersonal* is represented in the work of these four practicing engineer cases through the engineers' abilities to communicate and work with others. This included being able to both effectively communicate their own ideas and to be able to intake information that was communicated to them by a variety of audiences, including other engineers, coworkers, colleagues, or the public. In turn, this habit also captured how the engineers were able to remain open to new ideas that were presented to them by these varied audiences. Generating solution ideas and solving problems with other people necessitated the engineers to acknowledge perspectives and insights that may differ from their own. This idea was an important component to successfully remaining *Interpersonal* at the workplace. Additionally, the engineers were also cognizant of the skills, knowledge, and perspectives that were held by others. They recognized that the perspectives of others, including other engineers in different disciplines, stakeholders, or users of their products were valuable to the solution-generation process and should be accounted for when making decisions.

4.1.3 Habit of Mind 3: Self-Reflective

The third major habit of mind that was identified from the data analysis was the ability to remain *Self-reflective*. This habit arose from the grouping of the *Improving, Adapting, Managing impulsivity,* and *Attitudes* codes. This habit captured how the engineers reflected on their own actions, maintained personal composure, and expressed a positive attitude toward learning or problem solving. Table 4-6 provides a count of the number of instances that were coded with the habits of mind that comprised *Self-reflective.* Each individual element within *Self-reflective* varied in count between the engineers depending on the context in which the engineer worked.

Table 4-6

Number of Coded Excerpts for the Self-Reflective Habit of Mind.

Habit of mind	**Chemical engineer**	**Civil engineer**	**Electrical engineer**	**Biological engineer**
	Number of excerpts			
Self-reflective	303	36	260	215
Adapting	135	19	155	128
Attitudes	10	4	16	16
Improving	153	13	89	67
Managing impulsivity	5	0	0	4

One of the codes that was grouped into the *Self-reflective* habit was *Improving*. *Improving* was an a priori code from Lucas and Hanson's (2016) EHoM framework. This code was defined as "relentlessly trying to make things better by experimenting, designing, sketching, guessing, conjecturing, thought-experimenting, prototyping" (p. 6). *Adapting* was also an a priori code from the EHoM framework (Lucas & Hanson, 2016). It was defined as "testing, analyzing, reflecting, re-thinking, changing (physically and mentally)" (p. 6). Together, these two codes represented how the engineers sought to improve processes and designs at their company and reflected on previous solutions and their outcomes. *Improving* was grouped into *Self-reflective* because it represented the engineers' desire to improve both their company's products and their own problem-solving processes and approaches. *Adapting* was grouped into *Self-reflective* because it represented how the engineers reflected on the processes, tests, or solutions they had used before so they could be made better going forward. *Improving* and *Adapting* were often observed to be practiced in conjunction with another. *Improving* was a reflective practice that the engineers used after *Adapting*, such as when they analyzed and reflected on the data output from a test. After making observations about the data they collected, the engineers would then pose a new idea that would improve that data or would make the data collection more efficient. By employing both of these elements, the engineer cases were able to be *Self-reflective* in their experimentation, analysis, and interpretation processes as they solved problems.

Managing impulsivity was also incorporated into the *Self-reflective* habit of mind theme. This was an initial code that was generated during the first cycle of coding. The idea for this code was informed by Costa and Kallick's (2008) conceptualization of *Managing impulsivity* in their list of 16 habits of mind. The definition of the *Managing impulsivity* code for this study is "thinking before acting; remaining calm, thoughtful, and deliberative" (Costa & Kallick, 2008). This code represents how the engineers approached problems carefully and with thoughtful consideration. It captured how the engineers thought through problem definitions and solutions and considered the implications, impacts, or shortcomings of the solution they generated. *Managing impulsivity* afforded the engineers the time to process information and make informed, calm, rational decisions. This code was a *Self-reflective* process that characterized the engineers' professionalism, tact, and patience.

The final code that was grouped into *Self-reflective* was *Attitudes.* This was an a priori code from the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990). It was defined for this study as "having a positive disposition toward learning science, mathematics, and engineering." The *Attitudes* code captured evidence of the engineers maintaining a positive attitude toward learning, their job, and the field of engineering in general. This code was grouped into *Self-reflective* because it highlighted instances where the engineers were reflecting on their career path, their education, and engineering as a discipline. It represented how the engineers had a personal desire to pursue their chosen career path and remain interested in continuously learning and growing within their profession. Maintaining this positive outlook on learning and the engineering discipline motivated the engineers to find meaning in their work, seek challenges that would push them to grow intellectually and professionally, and recognize areas that they would like to pursue and learn more about in the future.

4.1.3.1 Self-Reflective Examples from the Data

The ability to remain *Self-reflective* was a habit of mind that was represented across all four of the engineer cases in different ways, depending on the context of the case. For example, the electrical engineer described how when he was starting to use a new tool, he ran some initial tests just to see what would come up as a result (*Adapting, Improving*). He stated during an interview,

> "And so, I had opened that, and I was opening the package of the tools that we had had, and I hooked up the, this won't really work without having something to sniff on, and right now I don't have any other than my wireless to the internal network here. I don't have any adaptors connected to anything. But this, let's see if I can bring anything up that might show any traffic at all. So that's, I'll just stop that. So that's traffic, it's mostly showing the internal computer, and then a lot of these sources, some of them are Ethernet addresses and some of them are MAC addresses, just depends on the protocol they're using."

This example demonstrates how the electrical engineer used the elements of *Improving* and *Adapting* that comprise the *Self-reflective* habit of mind. Having the desire to run tests, reflect on the results, and make decisions based on those results suggests the importance that this habit had on his work.

The biological engineer performed similar tasks when designing and evaluating the performance of the products that her company produced. When describing how a particular product was designed, she said,

> "Theoretically, all three [product]s were designed the same way to take the same amount of flow to split the flow between three [product]s. And we saw one [product] seem to be performing well and the other two showed signs of problems. And so we've taken a couple steps to try and figure out what might be different operationally or practice-wise. So we procured a flow meter. That's just it's an ultrasonic, you can strap it to the outside of a pipe. And it's not ideal for this application, but it would give us a sense of if the flow was evenly distributed."

This example highlights the importance of the *Improving* and *Adapting* elements toward problem solving. After analyzing and reflecting on the performance of several products, she and her colleagues recognized that two of them “showed signs of problems” (*Adapting*). She described how their team was going to use a flow meter device to measure the flow between these products (*Improving*) to determine what the cause of the problem might be.

The *Attitudes* code within the *Self-reflective* habit of mind is characterized by maintaining a positive attitude toward learning new concepts within engineering or toward the field of engineering in general. When asked about what he likes about his job, the civil engineer responded,

> “My job, I just like construction. I like building. I love the diversity. Some days I'm here working from 7:00 in the morning to 8:00 at night in the office. Some days I'm out in the field from 7:00 in the morning to 8:00 at night. Sometimes I've been out at wee hours of the morning on projects. I love that first workability. I just love it.”

This example shows how the civil engineer had a positive disposition toward his particular career and discipline of engineering. The electrical engineer similarly expressed the element of *Attitudes* when he acknowledged that there were certain aspects of his job that he did not particularly like, but he recognized that they were still important to his role and to the field of engineering. During an interview, he said,

> “I don't think most engineers love the paperwork side of it. I don't necessarily love it but I understand that it's necessary and I've seen enough of a need for it that most of the time I think I find that I have not enough time to create it, not that I don't want to.”

This positive attitude toward an aspect of his job that was not his favorite demonstrates that the electrical engineer had the ability to remain *Self-reflective* to recognize that there are components within engineering that have are valid and important but they may not necessarily be the most enjoyable.

The biological engineer also expressed the habit of *Self-reflective* as she maintained a positive attitude toward her job and the field of engineering. During an interview, she stated,

> "Yeah, rewarding is definitely that it's never boring and. Every day I feel challenged and sometimes it's a blessing and a curse. Some days it can be overwhelming when you're being asked to do five new things and you know, there's never enough time, but. I really enjoy working in a company that has all the different disciplines of engineering where I can hop on the phone or walk across the aisle to our electrical engineers or walk down the hall and talk with our chemical engineers. And so that's ... That's really rewarding. Every day, kind of get to learn something new every day."

This example shows how the biological engineer enjoyed her job and appreciated that her job was both rewarding and challenging.

Another way that being *Self-reflective* was represented in the engineers' work was through the element of *Managing impulsivity.* The chemical engineer expressed that an important part of being reflective at her job was through not acting on impulse and make judgements about someone else's ideas or perspectives. During an interview, she described,

> "But if you have the patience and the active listening skill set to take your ... To stop for a second, don't pass judgment. Tell me more. Ask some questions. What do you mean? Go show me. I find nine times out of ten there is a real problem in there that they're trying to communicate. They just don't know how. And sometimes they're wrong. I mean, that is true, but sometimes there is something real in there and it really takes a really strong, active listening skill set to find it."

This example demonstrates the importance of *Managing impulsivity* and being reflective about whether or not she was enacting a judgement on something before fully listening to her colleague's concern or issue.

Managing impulsivity relates to the importance of the habit of *Self-reflective* in order to make non-judgmental decisions and listen to others' perspectives. The biological engineer also demonstrated instances of *Managing impulsivity*, particularly when she was working with legal contracts between her company and other parties. During an interview, she described,

> "Even if we can show that it is their process that's not working, it still then would not be their responsibility to fix it or replace it. So the decisions that we're having to make, unfortunately, are not completely engineering or principle driven. It's also legal, contractually driven. And we just ... We have to be careful. Every decision we make, we have to make sure that we have permission in writing from our technology partner just in case it ends up that we need to replace the biology. And [company] doesn't have to bear the cost of that because it's very expensive."

The biological engineer demonstrated the element of *Managing impulsivity* by recognizing the importance of being thoughtful and deliberative when making decisions that may have legal repercussions. She emphasized the idea of being "careful" when making decisions about processes or items that may need to change throughout the duration of a project. This practice of being "careful" and deliberative when thinking about solutions was critical to her role as she made decisions from both engineering and legal standpoints.

These examples highlight how the habit of remaining *Self-reflective* is represented in the work of these four practicing engineer cases. Being *Self-reflective* is characterized by how the engineers reflected on their own actions, maintained personal composure, and expressed a positive attitude toward learning or problem solving. The ability to adapt to changing situations, reflect on previous experiences, and have the desire to improve processes were essential to maintaining a *Self-reflective* practice in the engineering workplace. Additionally, the ability to remain calm, thoughtful, and deliberative when presented with new information or when considering a decision was also essential to being *Self-reflective.* The engineers were also reflective when they expressed positive attitudes toward learning or toward their job as a whole. The ability to recognize the aspects of their job they enjoyed or felt challenged by contributed to this habit of mind and allowed the engineers to understand their strengths, interests, and areas they would like to invest time into learning to improve their skillsets.

4.1.4 Habit of Mind 4: Mindful of the Bigger Picture

The fourth habit that was identified from the data analysis was being *Mindful of the bigger picture*. This habit represented the codes of *Systems thinking*, *Visualizing*, and *Safety*. This habit described how the engineers approached problems and solutions holistically and how they considered the broader impacts of the work they were doing. This involved the ability to visualize and conceptualize engineering problems as complex processes that are comprised of individual components that affect the processes in unique ways.

The *Mindful of the bigger picture* habit of mind was shown in the data across all four of the engineer cases. Table 4-7 illustrates the number of counts of each of the individual codes that comprised *Mindful of the bigger picture* in each engineer's data. This table shows that all of the elements within *Mindful of the bigger picture* were represented in the work of each engineer, but the number of instances in which they demonstrated those habits of mind differed. This finding highlights how the representations of the *Mindful of the bigger picture* habit of mind were dependent on the context in which engineer worked.

Table 4-7

Number of Coded Excerpts for the Mindful of the Bigger Picture Habit of Mind.

Habit of mind	**Chemical engineer**	**Civil engineer**	**Electrical engineer**	**Biological engineer**
	Number of excerpts			
Mindful of the bigger picture	579	333	263	588
Safety	81	3	30	6
Systems thinking	461	206	151	495
Visualizing	37	124	82	87

One code that was grouped into *Mindful of the bigger picture* was *Systems thinking. Systems thinking* was an a priori code from the EHoM framework (Lucas & Hanson, 2016). This code was defined for this study as “seeing whole, systems and parts, and how they connect, pattern-sniffing, recognizing interdependencies, synthesizing” (p. 6). This code was grouped into *Mindful of the bigger picture* because it captured how the engineers viewed the processes and problems they were investigating as entire systems that were comprised of many complexly interrelated individual parts. It allowed the engineers to view their work as situated within a broader context that would inform how they made design decisions. When designing a solution, the engineers often had to consider not only their discipline-specific role, but also the components that would be implemented by other disciplines or groups within the company. The electrical engineer may have properly designed a wiring setup for a motor that was feasible electronically, but they would also have to consider the mechanical capabilities of the motor as well, such as whether the wiring setup that he designed would fit into the housing provided for the motor. The chemical engineer could design a production process that would improve the efficiency of her company’s output, but would need to consider whether that process was safe for her production line operators to use and interact with on the plant floor. This ability for the engineers to employ *Systems thinking* was critical to how they approached the design and development of solutions so that potential issues and considerations could be accounted for.

Safety was another code that was grouped into *Mindful of the bigger picture*. This was an initial code generated by the researcher during the first cycle of coding. This code was defined as “taking actions or making decisions to ensure the safety of employees, the public, or society in general.” This code was similar to *Systems thinking* in that it required the engineers to be thoughtful about how their individual solutions had broader impacts to a larger system. *Safety* was one of the elements that the engineers needed to be mindful of when finding solutions to problems. They needed to recognize that their ideas could be technically valid but may pose safety concerns when implemented in reality. The civil engineer needed to be aware of whether a site location was safe for construction if it was near people’s homes and public buildings. The biological engineer needed to ensure the biological reactions occurring in her company’s products were performing as intended so that clean water could be distributed to the sites that needed it. By always being aware of the *Safety* implications of their processes and solutions, the engineers were employing the habit of *Mindful of the bigger picture.*

Last, the code of *Visualizing* was grouped into *Mindful of the bigger picture.* This code was an a priori code from the Engineering Habits of Mind (EHoM) framework (Lucas & Hanson, 2016). It was defined for this study as “moving from abstract to concrete, manipulating materials, mentally rehearsing physical space and practical design solutions” (p. 6). This code was grouped into the *Mindful of the bigger picture* habit because it represented how the engineers were able to visualize solutions to problems in a broad context. When employing the element of *Visualizing*, the engineers viewed their proposed solutions or ideas in context with the larger problem they were trying to solve. They recognized their solutions were part of a system and needed to be compatible with all the other components of the system. Being able to *Visualize* their solutions and determine what was feasible, practical, and logical was an essential component to being able to remain *Mindful of the bigger picture.*

4.1.4.1 Mindful of the Bigger Picture Examples from the Data

The habit of mind of *Mindful of the bigger picture* was represented across all four of the engineer cases in different ways depending on the context of the case. For example, the biological engineer described how when her company was designing their products, they had to consider both the mechanical components and structure along with the biological processes that were occurring within the product. She described in an interview,

> "We learned some more insights into more of the, you know, the nitty gritty details. And so that's where we were trying to reconcile sort of the conceptual design that I had been trained with and a very meticulous mechanical design, and sometimes they do conflict, actually. The process, the conceptual is more focused on how biology, what environments biology really wants to operate in, and the mechanical design as just, you know, do you have the ... Like the pipe diameters that will allow for even distribution of the water. And sometimes those conflict, actually. So we've kind of gone through a process of trying to reconcile them."

This example shows how the biological engineer had to use the idea of *Systems thinking* in order to help be *Mindful of the bigger picture.* Her company's products had to be able to function biologically while also accounting for physical, mechanical limitations, like the size of pipes within the product. The civil engineer also engaged in the practice of using *Systems thinking* when solving problems. When reviewing comments regarding a particular project, the civil engineer indicated that there were several concepts he had to consider when conceptualizing the project. He stated,

> "Although it's two different projects I think they connect very much in both infrastructure and stormwater design. We're trying to make the connection there and I'm using my experience on the past project. That's what's driving a lot of the

> comments on this project too, the Geotech report, the stormwater design. It's just a huge balance I guess."

This example demonstrates how the civil engineer needed to consider influences from other reports containing varying types of technical information along with his previous project experiences when reviewing and critiquing an entire project. He indicated there was a need to strike a "balance" between all of the sources of information that comprised the overall project as a whole. In order to have a successful project, the civil engineer needed to consider all of the individual parts that could influence the outcome of the project.

Additionally, being *Mindful of the bigger picture* involved engineers recognizing that their products ultimately had a broader impact on the world outside of the company. This idea was represented in the engineers' work through the *Safety* element. For example, the chemical engineer often brought up a safety topic at the beginning of each meeting that she held with her colleagues. One of these instances occurred during an observation session. The field notes read,

> "Before they get started, [Chemical Engineer] says she wants bring up some 'Safety topics.' She says that she saw a good example of safety mitigation on the plant floor that she wanted to bring up. She says how someone was being very mindful of an intersection on the plant floor, and wanted to bring it to everyone's attention how they could all be mindful about safety risks in the workplace."

This example demonstrates how the chemical engineer wanted to integrate *Safety* into her company's culture. While much of her role was focused on production, forecasting, and evaluating manufacturing processes, she also took time to recognize that *Safety* was also an inherent, central component to effective operation of their company. This idea was also true for the electrical engineer's job. He participated in safety reviews with his colleagues to discuss possible areas of risk or hazards associated with their company's products. During an interview, he described these meetings:

> "And it's, they want people to, as they design stuff, be thinking about this and going through this process and making stuff inherently safer than it might be otherwise. Doesn't mean that something can't go wrong, it just means that the people who designed it actually thought, "Well, how could it go wrong?" and they said, "Oh, ok, well we could easily make it so this doesn't happen. And we can make it so the chances of this happening is much much less." Versus just throwing a product out there that was basically, "Oh well let's see how fast we can get this to meet this need." And considering nothing about safety."

This example shows how the electrical engineer had to think broadly about the products his company was producing, including the *Safety* considerations and how his company would address those potential risks when designing products.

In summary, the ability to be *Mindful of the bigger picture* was demonstrated in the work of these four practicing engineer cases through their approach to problem solving and solution strategizing. It encompasses how the engineers view problems as systems comprised of multiple parts that draw from different subject areas, account for physical limitations and feasibility, and acknowledge that engineering designs must uphold certain standards of safety. The engineers each had to be able to visualize how their products or processes would be implemented outside of their controlled testing environments or their design software. They had to consider the broader impacts of their work and how it affected the ultimate end-users or stakeholders of their products. The ability to be *Mindful of the bigger picture* and recognize that their work was situated within specific contexts that necessitated critical considerations was essential to how they generated solutions to problems.

4.1.5 Habit of Mind 5: Technically Adept

The final habit of mind that was identified from the data analysis was the ability to be *Technically adept*. This habit encompassed the codes of *Manipulation and observation* and *Computation.* This habit demonstrated how the engineers used physical manipulatives, testing setups, or computation tools to solve problems.

Similar to the other aforementioned habits of mind, the ability to be *Technically adept* was found to be represented in the data of all four engineer participants. Table 4-8 provides counts of the number of excerpts that demonstrated evidence of this habit of mind and the elements that comprised it. This table demonstrates how the ability to be *Technically adept* was represented across all four of the engineer cases. However, the varying counts indicate that the individual elements were represented differently depending on the context in which the engineer worked.

Table 4-8

Number of Coded Excerpts for the Technically Adept Habit of Mind.

Habit of mind	**Chemical engineer**	**Civil engineer**	**Electrical engineer**	**Biological engineer**
	Number of excerpts			
Technically adept	36	78	220	155
Computation	36	52	0	113
Manipulation and observation	0	26	220	42

One code that comprised the *Technically adept* habit of mind was *Manipulation and observation.* This code was an a priori code from the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990). This code was defined for this study as "using and handling physical manipulatives, making observations, and handling information." *Manipulation and observation* was included in the *Technically adept* habit of mind because it describes how the engineers worked with physical systems, components, or tools to contextualize and solve problems. This code included instances of the engineers making physical changes to their systems or prototypes, evaluating physical outcomes or results from their processes, or building physical components that they would then test and implement into a larger system design. This element was an important skill that allowed the engineers to make informed decisions about results that they saw or to make changes to a design using their own hands. Whether or not the engineers used this element of the *Technically adept* habit depended on their job role and context. Some of the engineers only engaged with computer systems and data, while others handled systems and manipulatives on-site or on the production floor.

The second code that comprised the *Technically adept* habit of mind was *Computation. Computation* was also an a priori code from the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990). This code was defined for this study as "using calculation and estimation skills in meaningful contexts to solve problems." This element was included in the *Technically adept* habit of mind because it demonstrated the engineers' ability to perform technical calculations and make conclusions based on them. This element was most commonly characterized by the engineers using computation programs on their computers or performing calculations on a calculator or in a spreadsheet. This element was also used depending on the context of the engineers' job role or function. Some of the engineers did not perform computations at all for their job, while others worked closely with computation programs that dictated how they designed solutions to problems.

4.1.5.1 Technically Adept Examples from the Data

The *Technically adept* habit of mind was present in all four of the engineer case data. Similar to the other four habits of mind, the ability to be *Technically adept* was also represented differently in the engineer case data depending on the context of the case.

Being *Technically adept* was represented in the work of the chemical engineer when she worked with spreadsheet programs to analyze and manipulate data regarding production output and efficiency of the production lines that she oversaw. During an interview, she described,

> "So somewhere over the summer, I started collecting my own data. Well, in that data collection process, because I'm building a new standard and I didn't know if I would need it or not, I thought it was a good idea. I thought I would track the current planning rate that we're being planned to in this ... In the file where I'm collecting how many pounds we ran so I could check the variance. OK. Did we make our pounds or not? Right. Were we close to target or not?"

This quote demonstrated how the chemical engineer collected data and ran analyses on it. She used *Computation* abilities to manipulate the data and check the variance, whether their company achieved their production goal, and how they close they were to their target goal. During another interview, she also described,

> "So that's the one I was referencing few questions back about aligning on reason codes and tracking the overall gap of why my attainment was off for the week. Because there's been no home for that information. So I created that data table so that over time, as ... as our knowledge base grows, we're logging those reasons, assigning variances to them. I built it so it could be pivot tabled. So that we can

> extract some data out of it later for trending and ultimately for how to continue to improve the process."

This quote further explicates how the chemical engineer collected and analyzed data within the context of her job. She described how she purposefully built a data table that could be easily manipulated to extract relevant information from it. She used her ability to be *Technically adept* to design the system in this way so it could be effectively used to improve their production processes going forward.

The *Technically adept* habit of mind was also commonly represented in the work of the electrical engineer, as the nature of his work involved him frequently running tests on physical objects at his workplace. During an observation session, the researcher observed him wiring a harness onto a test unit and then preparing the wires for testing. The field notes read,

> "He clips some of the wires into a harness. He then clips the harness onto the VCU unit. He brings over something else from across the plant, some kind of torch device. He runs it over the ends of some wires that are free and sticking out of the harness that's plugged in. It looks like he's melting some black plastic that's around the wire ends."

This example demonstrates how the electrical engineer handled physical manipulatives for his job in order to prepare their products for testing (*Manipulation and observation*). However, analysis of the electrical engineer's data revealed no instances of the *Computation* code. He did not use calculators or computation programs to numerically manipulate numbers as part of his job.

The civil engineer, on the other hand, often employed *Computation* in conjunction with *Manipulation and observation.* During an observation, the researcher noticed that he was using a calculator and a scale simultaneously to generate numerical information and record it on a set of map plan documents. When asked about this process, the civil engineer described,

> "I was trying to quantify, through scaling and other methods, how much reduction, how much asphalt and concrete they would not have to remove and replace, and make the adjustment from 8,400 square feet down to what would be required to complete the project."

This example demonstrates how the civil engineer used a scaling tool (*Manipulation and observation*) along with calculator computations (*Computation*) to determine numerical values that would help him solve the problem he was working on.

The biological engineer also used *Computation* skills to solve problems at her workplace. She would often run calculations in an Excel program that she built to obtain particular output values related to her company's products. During one of the observation sessions, the researcher observed her,

> "To one of the rows labeled "Solution strength", under "Step 5: Acetic acid", she adds "60%." The values in the tables update. She reads over them. One of the rows is labeled "Contingency for non-ideal conditions" and she inputs "30%" here. She reads over the updated numbers, then writes something down in her notebook. She reads over more numbers and then adds them to her notebook."

During this same observation, the biological engineer verified her Excel calculations by performing several of the computations by hand in her notebook. When interviewed about this process, she indicated that it was important to verify the numbers obtained in the program by hand to check for errors or inconsistencies in units or the numbers. She stated,

> "I will rerun it by hand once every five times just to make sure all my units are consistent and I'm not off in left field somewhere before I send it on for another review."

This example shows how the element of *Computation* was essential to the biological engineer's work. She needed to be able to run computational design programs to obtain information about her company's designs. She also needed to be able to perform hand calculations to verify the computations performed in the design program.

The biological engineer also demonstrated instances of *Manipulation and observation.* She indicated that she would often perform tests and observations of her company's products in order to troubleshoot and observe the reactions that were taking place. She stated,

> "So I went out, did exactly that, took out all 450 gallons. I still can't feel my arms. We took it down. We sent samples back to the lab. We got a report which supported the hypothesis that it was growth, not scaling. We sent in a 50 milligram-ish sample and the lab results revealed that 20 of those 50 milligrams was biological growth, which is not what we would expect based on this particular process design. We would expect 10 or less by far. And so it supported the hypothesis that most of our problems were due to bio growth."

This example highlights an instance where the biological engineer went on-site to observe biological processes and troubleshoot the issues that they had observed. Her physical observations of the biology were critical to the problem-solving process and generating ideas about how to improve their processes.

These examples suggest the importance that embodying elements of being *Technically adept* has in the work of practicing engineers. Engineers often to have to run calculations to verify information or make decisions about how solve a problem. Depending on the nature of their job, they may also have to construct and run tests on physical prototypes of the products that they design to determine if the system operates as intended and if the results are as anticipated. Performing tests using physical manipulatives may also provide insights into the quality of the test being performed as well and whether the test plan itself is accurate and providing credible information.

4.2 Within-Case Analysis

The following sections (4.2.1 through 4.2.4) provide details about the within-case analysis of each of the four engineer cases. These sections first outline the top three most comment elements of the five habits of mind that were identified in each engineer's dataset. Reflective memos that were written by the researcher are then provided to provide insight into each engineer's working environment. Last, notes that the researcher took during member-checking sessions with engineers who were available to conduct them are presented.

4.2.1 Chemical Engineer

One of the engineer cases that was analyzed in this study was the chemical engineer. As described in Section 3.9.2.3, the chemical engineer worked in a management role at a large manufacturing plant in a large, publicly-traded company in the United States. Her role was primarily in the management of people, processes, and operations with a focus on ensuring efficiency and productivity of her employees and the manufacturing processes in the company. Table 4-9 provides a count of the number of excerpts that were coded for each of the five habits of mind and the corresponding ways in which they were enacted. This table demonstrates how all five of the habits of mind were represented in the chemical engineer's data, but the frequency in which she used each habit of mind was dependent on her role and workplace context.

The following section will describe the top three most common codes that were found in the analysis of the chemical engineer's data and how these elements were represented in her work. Section 4.2.1.1 provides a reflective memo written by the researcher to provide contextualizing information about the chemical engineer’s workplace and the environment in which the on-site observations with this engineer were conducted. Section 4.2.1.2 then describes the notes that the researcher took during the member-checking session with the chemical engineer. These notes highlight the chemical engineer’s perspectives on the results obtained from the analysis of her data.

Table 4-9

Within-Case Results from Analysis of the Chemical Engineer's Data.

Habit of mind	**Number of excerpts**	**Definition**
Problem-focused	1341	How the engineers engage in the problem solving process, e.g., through investigating, evaluating, or generating solutions to problems
Critical response	181	
Curiosity	259	
Engineering judgement	18	
Informed skepticism	98	
Problem finding	780	
Transparency	5	
Interpersonal	1241	How the engineers communicate and work with others
Acknowledgement	75	
Communication	597	
Creative problem-solving	501	
Openness to new ideas	68	
Self-reflective	303	How the engineers reflect on their own actions, maintain personal composure, and express a positive attitude toward learning or problem solving
Adapting	135	

Attitudes	10	
Improving	153	
Managing impulsivity	5	
Mindful of the bigger picture	579	How the engineers approach problems and solutions holistically and consider the broader impacts of their work
Safety	81	
Systems thinking	461	
Visualizing	37	
Technically adept	36	How the engineers use technical tools, such as physical manipulatives, testing setups, or computation tools, during their work
Computation	36	
Manipulation and observation	0	

The most common codes that occurred in the chemical engineer's dataset included *Problem finding*, *Communication*, and *Creative problem-solving.*

Problem finding was defined for this study as "clarifying needs, checking existing solutions, investigating contexts, and verifying" (Lucas & Hanson, 2016, p. 6). This code was represented in this engineer's work when she would clarify problem contexts with colleagues during meetings or would seek to obtain feedback from colleagues on the effectiveness of a new process that she implemented. During an observation session in which the chemical engineer was attending a meeting with multiple other colleagues, the researcher noted a discussion the group was having about the best location on the production line to implement a new process strategy. The field notes read,

> "They [the group] continue talking about where it would be best to implement these strategies – "boxes or bags?" and "What is the best cell to have a centerline?" They discuss what method would "add the most value to the company?" They continue discussing some logistics behind the processes that they are proposing."

This instance demonstrates an example of *Problem finding* because the chemical engineer and her colleagues were establishing the context of the problem they were trying to solve, as well as the context of the solution that they were weighing. These types of conversations commonly took place during the observations with this engineer.

Another example of the chemical engineer employing the code of *Problem finding* was when she sought to understand the needs of other employees regarding using process tools or strategies that she developed for them. During an interview, she described how when their team made decisions about their next steps, it was important to her that they were all in agreement about what those next steps would be. She stated,

> “Now, where do we want to go from here? You know, and that's where [colleague] was like ... Because we at that point exhausted all the time. And he said, "like, I'd like to understand what you think the next steps are." And that's when I kind of hurried into ... I think I skipped ... I skipped a slide for what's working, what's not working and went right into next step. But I kind of bebopped back and forth to kind of connect dots. So it was rushed, though, because I think there's a real healthy debate on what's next. There was alignment. I agree that there's some standards that need to be made. I do 100 percent agree with that. But we need to align on who's going to do them, when they're going to do them and all that kind of stuff. And so, anyhow, it ended there. And I just need to set up another time for us to get back together with probably a proposal now on how that move forward plan looks. So, a Gantt chart of something, project charter. What are we trying to accomplish?”

This example demonstrates how the chemical engineer wanted to clarify the needs of other employees who were involved in the project or process that she was working on and wanted to acknowledge that there would be multiple ways to approach a given problem. The process of understanding the team’s next steps from her own perspective in conjunction with the perspectives of others was essential to her process of *Problem finding.*

The next most common code represented in this engineer’s work was *Communication.* This code is characterized by the engineer listening thoughtfully to the ideas and perspectives of others as well as being able to effectively communicate their own ideas to a variety of audiences. Much of the chemical engineer’s work involved active communication and collaboration with her fellow employees, including other engineers, operators, and marketing personnel. She described her role as,

> “I don't know if this is like fair, but I'm like "I think I'm a social engineer." Well, like, because I ... it's my whole deal is to try and figure out at work, like, how to bring people into process and make it all fit. And how do you engineer a team? How do you bring them together and get them to align on something and move in the same direction? I'm like ... I'm totally like social engineering.”

This quote demonstrates how the chemical engineer viewed her primary role as managing and interacting with her employees and team members.

She also emphasized the importance of getting feedback from these different stakeholders on the processes and systems she implemented to make them better for those individuals' daily work lives. During an interview, she stated,

> "I basically went and talked to our CI manager and I may have talked to a couple of my supervisors and said, "hey, what kind of feedback do you guys have that you think ... What do we ... What should we be talking about with new people when they start from our perspective? What would you like me to talk about with them or what do you want me to cover?" And I threw out a couple of suggestions on email. They replied back and I pretty much gathered some brainstorming thoughts and just kind of threw them down on the ... on that PowerPoint."

This example demonstrates how the chemical engineer was actively listening to and being understanding of the line supervisors' needs. She had to have strong *Communication* and *Creative problem-solving* abilities to effectively recognize where other employees needed support and how she would improve her processes or production tools going forward. Similarly, the researcher observed her creating documents and templates with feedback from the users in mind. The field notes from this observation read: "She says that this is a new template for a new meeting that they are having next week. She says that she had revised it based on feedback and suggestions that she received from previous meetings." These examples demonstrate how *Communication* and *Creative problem-solving* were represented in this engineer's work. Generating solutions to problems with others and listening to their perspectives and ideas were foundational to her role and the work that she performed.

Additionally, during the first cycle of coding of this engineer's data, the code for *Acknowledgement* as a *Value* became apparent to the researcher. This code captured the idea of recognizing the contributions, specialties, and perspectives of others. The researcher defined this code in the codebook as “realizing and recognizing the work, effort, contributions, accomplishments, and ideas of others.” In addition to being able to listen to the ideas of others with understanding (*Communication*), the chemical engineer actively took feedback from the colleagues that were using the production tools that she developed and used their ideas to improve and refine these tools (*Acknowledgement*). She continuously sought to include the relevant stakeholders in the design process, acknowledging their opinions and using them to refine her own ideas. The researcher observed one instance of her demonstrating *Acknowledgement* at the workplace during a meeting with the line operators who were using a tool that she implemented on the production floor. The field notes read,

> “[The chemical engineer] goes back to the “Agenda” sheet in the Weekly Meeting file and summarizes what they talked about at this meeting today. She says that she wanted to “say thank you to you and your leads for adjusting to the new shutdown planning” system that had been implemented recently. She says that they’ve gotten “good engagement” with the new system. She says, “Thank you for working with your teams to tackle something new and try to own it.” She says that she also wants to “recognize people for their efforts during COVID-19” since “everyone has stepped in and helped” when it was needed. She asks the room if there is anything else they’d like to recognize here at the meeting? The room discusses.”

This quote highlights the importance that the chemical engineer placed on getting feedback from the employees she worked with in order to improve the processes for everyone involved.

The chemical engineer further emphasized the importance of *Acknowledgement* when describing how she solicited feedback from those who were using her tools. During an interview, she described this process:

> "So when we go through the process of engaging our front line leaders, which we'll do next month, to be part of designing what we're going to measure, allowing them that space to design it means that they get to decide, not [colleagues] and me."

This example further highlights how the chemical engineer employed the use of *Acknowledgement* in her role. She described how she explicitly wanted to involve the operators and technicians that used the tools she developed in refining and improving those tools. Their opinions and input were important to her as she continued to improve processes at her company.

She also described how high quality documents from her perspective would be ones that were reviewed multiple times to gain various perspectives and ensure that all of the employees were in agreement on their processes, approaches, or solutions. She said,

> "I'm trying to ... To turn it into a high quality document I am actually translating it into an Excel agenda that I've now floated to two people who weren't in the room, but to appear and know my leader, to get alignment on what we think we're doing. And then I'm going to make sure my team reviews it on our Monday meeting to say, is this what we discussed? So a high quality document. One that's been reviewed and again, and transparently, people say, yeah, that is what we were ... We were thinking, or that's what we are saying. That looks right."

This example demonstrates how the chemical engineer actively sought feedback on the work she produced. It was important to her that she obtained "alignment on what we think we're doing" from her fellow employees in an effort to be inclusive in her efforts to improve the work that she performed.

She also described that when she revised documents or tools, the feedback and perspectives from the employees and stakeholders who would be using those documents or tools was essential. When asked about what sources she would consult during the revision of these documents, she said,

> “My stakeholders. So whoever I think is going to end up being the audience. Not so much the audience, whoever is the stakeholder and how that generate ... Data got generated for sure needs to have input to it. That's why I've gone out of my way to make sure my materials and planner and technical manager and my C.I. manager have all seen how I'm doing this. Because over time, if we start to present this data as a source of truth on what's driving us and we can detect when issues are happening because I now have a state of normal as well out of this. I need those key stakeholders to be, right, aligned that that data is relevant and it's solid. So they ... they have to be in there as having input to the content.”

This quote shows how the chemical engineer found it essential to obtain the perspectives from the stakeholders that would use the tools she developed. She wanted to ensure that all of the relevant people “have all seen how [she is] doing this.” She wanted to be open with these stakeholders about the work she was performing and wanted their feedback and perspectives on whether they were in “alignment” with her ideas.

These examples all demonstrate how *Acknowledgement* was represented in the chemical engineer’s work. She paid special attention to the opinions, perspectives, and feedback offered by other engineers, line operators, or other stakeholders in the production cycle. These perspectives were central to her revision process of the documents and tools she created.

Another code that was generated during the first cycle coding analysis of the chemical engineer’s data was *Managing impulsivity.* This code is defined in the codebook as “thinking before acting; remaining calm, thoughtful, and deliberative” and was derived from one of the habits of mind proposed by Costa and Kallick (2008). She described during an interview,

> “I had a situation happen over the weekend that I was incredibly frustrated about and decided as opposed to venting, to channel my energy and into developing an expectation that might ground us for a discussion. So was it critical for the day? No. Is it a critical pattern? I kind of see to our ability to execute, yes. It was probably the 10th time I'd seen something that, OK, we need to resolve this little issue. And maybe what's best is me setting a new expectation.”

This example highlights an instance where the chemical engineer purposefully remained calm and deliberative when choosing how to approach a problem. She described how she was frustrated and could have acted on impulse, but that she instead chose to remain thoughtful and “channel [her] energy” into a solution that would be productive for the rest of the team. During another instance, she described a situation where she disagreed with what a colleague had said and wanted to interject:

> “So she had picked some very detailed items for objectives. As in lot code accuracy needs to improve and LP accuracy needs to improve. And I was tactfully trying to interject a point, as in I ... that's not an objective, that's an initiative. And the objective is we need to deliver product right first time. She wanted to call it "reduce holds." Either way, you're talking about the same thing. And that's what we ended up aligning on for the content for the A3.”

This example shows how the chemical engineer was mindful of trying to interject tactfully and correct her coworker’s mistake. Her ability to *Manage impulsivity* was important because it allowed her to act with integrity and deliberation rather than on impulse or emotions.

A third code that was generated by the researcher during the first cycle of coding was *Safety*. This code was defined in the codebook as, “taking actions or making decisions to ensure the safety of employees, the public, or society in general.” The chemical engineer often worked with colleagues to determine where safety issues might occur or be documented for various processes. During one instance, the researcher observed,

> “Someone comes into her office then, discussing their own sheet that’s in the A3 Strategy document. They discuss one of the items, adding one to the ‘System Standardization’ heading in this sheet. They discuss where certain items best belong. [The chemical engineer] says that they should ‘align this to reduce the safety risk.’ She references the paper as they continue placing items in different

> sections in the Excel sheet. She types, 'Reduce Safety Risk in Operations.' She says that 'this is a lock out tag out as well.'"

This demonstrates how *Safety* was a consideration for the chemical engineer when she and her team were creating processes that ultimately guided how the employees performed their work. She and her colleague in this instance were working to "reduce the safety risk" of a particular process and ensure that areas where safety should be enforced were documented in the appropriate location on their company documentation.

The analysis of the chemical engineer's data revealed no instances of *Manipulation and observation*. This engineer did not handle physical manipulatives or make direct observations of the systems that she was analyzing. She interpreted summary data that were generated from automated systems, manual entry, or were presented to her by other colleagues. She did not directly observe or enter in the data that she was analyzing.

4.2.1.1 Chemical Engineer Reflective Memo

Reflecting on the experience of conducting the on-site observations with the chemical engineer revealed insights into how she used habits of mind at the workplace. Reflecting on this experience also provided contextualizing information about the nature of the chemical engineer's work environment and the details of how her day-to-day workplace behaviors were expressed. These contextualizing details helped provide a deep understanding of how habits of mind were represented in her unique workplace culture and context. This reflective memo will first describe the details about the environment in which the chemical engineer worked, including what it was like to observe at the company in general and what the physical space looked and felt like. The reflective memo will then describe the types of activities that I observed the chemical engineer engaging in and how she interacted with others throughout her work day. Connections to the top three habits of mind elements that were identified in the analysis of her data (as described in Section 4.2.1) will then be made from the details that I reflected upon.

The company at which the chemical engineer worked required visitors to sign in at the desk and then proceed through a changing room to put on a work-coat and shoe coverings. I did this process each time I visited the company. They did this to ensure there would be no contamination within the facility. Other employees in the facility often wore hard hats, hair coverings, and safety glasses or goggles. The chemical engineer told me that most employees kept a set of shoes within the changing room that did not leave the facility so they would not have to wear shoe coverings. She also described how if we were to go onto the production floor, we would not be allowed to wear any kind of jewelry or watches. Additionally, all personnel and visitors were required to wear long pants and closed toed shoes and long hair had to be tied back.

The physical office space was made up of both open offices and individual offices within their own rooms. The chemical engineer had her own individual office with a door. There was a large whiteboard on one wall. She had a dual-monitor computer that could connect to a large TV monitor mounted on the wall near the door to the office. I would sit on a chair across from her desk when I observed her.

The chemical engineer performed individual work in her office, such as updating Excel spreadsheets, reviewing emails, creating presentations, and forecasting and validating information obtained from the production lines. She also frequently consulted other colleagues at their desks, in their offices, in conference rooms, or in her own office.

This demonstrated how she would enact the element of *Creative problem-solving* as she maintained the habit of being *Interpersonal*. *Creative problem-solving* was further manifested in her work as most of my observations involved seeing her interact with one or more colleagues during the session. She would jointly create presentations with colleagues to solicit their feedback on the information she was presenting. In other instances, she would discuss budgeting and forecasting amounts with a colleague at another site location on the phone while they reviewed the same Excel file simultaneously. These instances of her work also suggested the relevance that the *Communication* element of being *Interpersonal* had in her daily work. She had to be able to listen to the perspectives of others and incorporate their feedback in a meaningful way.

During these observations, the chemical engineer and I also attended group meetings consisting of two to 10 people depending on the meeting. We would sit in an open office area with a central table and whiteboard on one wall or in a conference room with a table and TV monitor on one wall. When observing her during meetings, I would sit in an unoccupied chair at the central table or conference table. These meetings fostered the chemical engineer's use of the *Problem finding* element of being *Problem-focused* and the *Creative problem-solving* and *Communication* elements of being *Interpersonal*. She engaged in defining and contextualizing problems (*Problem finding*) with other engineers and stakeholders (*Creative problem-solving*) and also generated solutions and action items based off of the perspectives gathered from everyone in the group (*Communication*).

4.2.1.2 Member Check with the Chemical Engineer

The member checking session with the chemical engineer was conducted virtually using the Zoom platform. Prior to the member checking session, the researcher emailed the chemical engineer a summary of the findings from the analysis of her data along with descriptions of the five habits of mind that were generated from the analysis. The engineer was provided with a count of the number of excerpts associated with each code that was present in her data and a summary of the top three most common codes based on the counts. A sample of the member checking questions that were used during the session are presented in APPENDIX B.

During the session, the chemical engineer stated that she agreed with the interpretations that the researcher made about her top three codes. She then provided her insights on some of the individual codes that were identified in her data. She noted that the code of *Acknowledgement* was not something that she was taught to employ as a classical, technically trained engineer. She described how in her role at her company, she was often performing activities such as problem solving with a team, managing and fostering teamwork with her employees, and learning how to articulate her thoughts to a variety of audiences. She said that learning how to acknowledge the perspectives of others and communicate effectively with them was essential: “not doing that gets you into trouble with your operators.” Similarly, she described how engineers “don’t see themselves as leaders” and may not realize the impacts that they can have on fellow employees or others that they work with.

The researcher then asked the chemical engineer to provide her perspectives on the five habits of mind that were identified during the data analysis, including being

Problem-focused, Interpersonal, Self-reflective, Mindful of the bigger picture, and *Technically adept.* For *Self-reflective,* she said that the idea of "emotional intelligence" was important to her when she was reflecting on her actions. She described how to her, this meant that she was aware of how she was appearing to others and the impressions that her decisions and actions made on others. She also stated that she was mindful of the things that she could bring to "shape others' opinions" when working on solutions.

Additionally, the chemical engineer stated that it was important to make sure that her operators and technicians felt that their perspectives were valued in the workplace. She said that it was important to her to "value open, honest feedback" and that "everyone is important" when there are problems to be solved. She said she strived to ensure that her operators' and technicians' voices were heard. It was important to her to involve non-scientific thinkers into the problem solving process because she wanted to be able to positively influence their beliefs regarding the types of decisions that she made that would directly impact them.

For *Mindful of the bigger picture,* the chemical engineer described how if she was not able to view a problem in its entirety, it would be "task-managed to death." She said that she was able to be more astute if she were able to think ahead during the problem-solving process, identify what steps would need to be taken to arrive at a solution, and determine what those steps looked like specifically.

When asked about the *Technically adept* habit of mind, the chemical engineer described that for her job, the *Computation* component was key. She said that in her role, "statistics is huge" and the ability for her to identify variability in data and determine whether it is accurate was essential. She commented that in her engineering education, learning the theoretical concepts of subjects like calculus were important, but that the ability to manipulate and evaluate data was more crucial to her everyday work.

The researcher then asked for the chemical engineer's perspectives on being *Interpersonal.* She described how essential it was for engineers to be able to communicate effectively with one another and in her case, the operators working on the production lines that she managed. She said that someone could be a very "gifted engineer, but if you can't communicate effectively" and bring your ideas "with you," it "renders you ineffective." She said that the idea of employing the *Interpersonal* habit of mind fit her belief about how engineers should strive to have the skills necessary to communicate and collaborate with others. The chemical engineer also noted that it was important to be able to gauge the audience to whom she was communicating. She said that "talking with engineers is very different from talking with non-engineers" and being able to effectively communicate with either type of audience was crucial to her work.

The chemical engineer then shared that she felt that she "excelled" in the *Interpersonal* habit of mind. She said that these abilities developed over time and that she did not feel its importance was something that was communicated to engineers who were early in their careers. She commented that general perceptions of engineers do not typically account for the *Interpersonal* habit of mind, and she wondered "how much of the engineering talent pool is diminished" because of people who did not realize their skills would be useful in an engineering context.

The chemical engineer also commented that when solving problems with others, it was crucial to "attack the process" versus "attacking people's ideas." She said that it was important to investigate what factors may be affecting a certain problem and validate the presence of these factors with data instead of immediately discrediting someone's idea about how to solve a problem.

4.2.2 Civil Engineer

Another engineer case that was analyzed in this study was the civil engineer. As described in Section 3.9.2.4, the civil engineer worked at a small, not-for-profit government engineering organization in a city in the United States. He was a licensed Professional Engineer that provided high-level oversight on projects and decisions and managed the people, processes, and stakeholders involved in various engineering projects. Table 4-10 provides a count of the number of excerpts that were coded for each of the five habits of mind and the corresponding ways in which they were enacted for the civil engineer. This table provides evidence that all five of the identified habits of mind were represented in the civil engineer's work. The table also demonstrates how the individual elements that comprised the five broad habits were represented in the civil engineer's data that were dependent on the context of his work.

The following section will describe the top three most common individual elements that were found in the analysis of the chemical engineer's data and how these elements were represented in his work. Section 4.2.2.1 provides a reflective memo written by the researcher to provide contextualizing information about the civil engineer's workplace and the environment in which the on-site observations with this engineer were conducted.

Table 4-10

Within-Case Results from Analysis of the Civil Engineer's Data.

Habit of mind	Number of excerpts	Definition
Problem-focused	907	How the engineers engage in the problem solving process, e.g., through investigating, evaluating, or generating solutions to problems
Critical response	162	
Curiosity	115	
Engineering judgement	84	
Informed skepticism	76	
Problem finding	465	
Transparency	5	
Interpersonal	359	How the engineers communicate and work with others
Acknowledgement	16	
Communication	196	
Creative problem-solving	118	
Openness to new ideas	29	
Self-reflective	36	How the engineers reflect on their own actions, maintain personal composure, and express a positive attitude toward learning or problem solving
Adapting	19	
Attitudes	4	
Improving	13	

Managing impulsivity	0	
Mindful of the bigger picture	333	How the engineers approach problems and solutions holistically and consider the broader impacts of the work their work
Safety	3	
Systems thinking	206	
Visualizing	124	
Technically adept	78	How the engineers use technical tools, such as physical manipulatives, testing setups, or computation tools, during their work
Computation	52	
Manipulation and observation	26	

The most common codes that occurred in the civil engineer's dataset included *Problem finding*, *Systems thinking*, and *Communication*.

The code of *Problem finding* was the most common code that was represented in the analysis of the civil engineer's data. He frequently compared multiple documents or sources of information against one another to verify their accuracy for their intended purpose. During one of the observations, the researcher observed him comparing information from a map demonstrating the development of an area under construction to a document where he was typing information about tasks that needed to be completed in this area of the map before work could be done. In this instance, he was both verifying and investigating the context of the area under consideration so that he could make a recommendation about what work should be done in these areas.

In another instance, he compared information presented in a document to a book of standards and specifications. He compared information presented about the physical properties that were obtained about a site from testing to what was presented in the document, while also referencing the standards of specification book. When interviewed about these actions, he commented,

> "So, the document on the right, the [State] DOT road base for untreated road base is the submittal for a project that I bid last year and we're getting ready to construct. They're actually gonna start construction on the 19th of this month. So, it's part of that process, we want to make sure that all the materials that they're proposing to use meet the standards that specify for the project. So, the one on the right is their submittal for their proposed material. The one on the left is actual project specific notes. Those are basically what we're specifying that this material should meet. That was taken out of the [State] DOT standards and specifications, so there's a breakdown of section 2, 2.13, 2.8, and then section 3 down there. Basically, then what I would be doing is making sure that that submittal meets that specification."

These examples demonstrate how *Problem finding* was represented in the work of the civil engineer as he sought to establish the context of problems and verify information about the construction of a project.

The next most common code in the civil engineer's data was *Communication.* This element was defined as "transferring ideas clearly and to read and listen with understanding" (Rutherford & Ahlgren, 1990). This engineer described *Communication* as being foundational to his role within his company. He described the nature of his job in an interview:

> "A lot of people like the younger folks they probably didn't appreciate it because it wasn't quantifying, running calculations and things but for the most part my job, I don't run calculations all day. I write. I communicate all day. The biggest focus of my day is writing an email depending on who it's to that made, it may dictate what tone I use or even expressions or terms."

This quote highlights how he viewed interactions with others as central to his work as an engineer. He stated that he "communicate[s] all day" rather than performing calculations. This demonstrates that importance that the *Communication* code had for the civil engineer's work.

He also described how he frequently interacted with stakeholders, including other engineers, political personnel, and the public, due to the nature of his job, when making decisions about how to solve problems. He noted that for one project,

> "We don't include the building department, but we have the fire department. We have public works, water, wastewater, streets, stormwater, and backflow, and light and power in those reviews."

This example provides insight into the types of stakeholders that the civil engineer interacted with frequently to solve problems. He described how he needed to be in

Communication with various departments within his company in order to accomplish work tasks.

These examples demonstrate instances of the civil engineer making use of the code of *Communication.* The nature of the civil engineer's work necessitated that he was able to listen to other perspectives about solutions with understanding and to give them a fair weight when making decisions. Additionally, he had to be able to communicate his ideas and solutions effectively to a variety of audiences, including different departments within the municipality, to the mayor of the city, or to the general public.

The third most common code represented in the civil engineer's work was *Systems thinking.* This habit is defined as "seeing whole, systems and parts, and how they connect, pattern-sniffing, recognizing interdependencies, [and] synthesizing" (Lucas & Hanson, 2016, p. 6). This engineer frequently employed the code of *Systems thinking* when solving problems. This code is characterized by being able to identify and synthesize the patterns between different parts of a system and how they interact with one another. When reviewing information in different documents, he would frequently seek to verify that information based on what he already knew about the system and how any new changes would affect that system going forward. During an interview, he stated,

> "So, the reason I looked at several different perspectives was that they had certain information, but it was only a micro-level of information. So, I was able to get on my maps and look at it at more of a macro-level…. I was able with my tools, to look at it on a macro-level and verify that yeah, we're gonna have issues constructability. Where are we gonna bring this line, this is all really steep. How are we gonna get the equipment in there to get to it, so that's kinda what I was doing and just verifying different aspects and different scales. I also was looking at their proposed water lines, or distribution lines and I don't know if you saw I was also making sure theirs was accurate compared to ours, and I was verifying this report and making sure it was right."

This example demonstrates how the civil engineer had to consider different parts that comprised the whole issue, or system, he was analyzing. He had to consider how equipment would be brought to the site, the steepness of the ground near the area they would be working on, and whether or not the locations of the water and distribution lines were accurate.

Another instance of the civil engineer using the code of *Systems thinking* was when he was reviewing documents for compliance to the city's standards and specifications. During an interview, he described,

> "I'm reviewing for compliance to our city standards and specifications. And that's where this document that you're gonna have me read later, that's what we were doing there. Or what I was doing. I was going through these submittals and verifying compliance with our standards. So, I use a multitude of references for that."

This example demonstrates how the civil engineer kept compliance in mind as a central system and explored how different parts of the documents he was reading either adhered to or were out of compliance with the city's standards and specifications. This code was readily apparent in the civil engineer's daily work as he reviewed construction proposals, reviews, and demolition plans.

The code of *Engineering judgement* arose during the first cycle coding analysis of the civil engineer's data. This code is defined in the codebook as, "Making decisions about engineering-related concepts. Using expertise as an engineer to make decisions that potentially affect others, such as whether or not a design meets standards or specifications." When asked about how he decided whether or not to send a document for approval, he responded,

> "That's a really good question and I think that's a really difficult question actually. It's basically a judgment. If I see a borderline product that barely meets the

> standard or specification and it's three years old, I will call for another one. If I see one that's well within the standards or spec, you're not following a fine line on one side or the other it could very ... Well, I guess what I'm saying is if a little variation in that doesn't make it out of compliance then I would accept one that's a little older. Six months, maybe up to a year."

This example shows how the civil engineer evaluated both the age of the information he was considering as well as how well the information aligned with the standards and specifications his company abided by in their work. He indicated that decisions are not always straightforward, and he had to use some of his engineering expertise or *Engineering judgement* to identify what an acceptable variation from these standards might be. This element was important to his role within his company as he had the authority to make these kinds of judgements based on his knowledge and training within the civil engineering discipline.

The analysis of the civil engineer's data revealed no instances of *Managing impulsivity*. There were no identified instances of the data in which the civil engineer acknowledged that he would have to remain thoughtful and deliberative when listening to the perspectives of others or making decisions. This does not indicate that the civil engineer acted on impulse or did not remain thoughtful or deliberative, but there were no instances in the data where he explicitly demonstrated this habit of mind.

4.2.2.1 Civil Engineer Reflective Memo

By reflecting on the experience I had conducting the on-site observations at the civil engineer's workplace, I was able to generate insights about how he used habits of mind at his company in the context of his unique workplace environment. This reflection provides insights into the nature of his daily work scope and environment to demonstrate the ways in which habits of mind were represented in his work. Detailed information about his physical work space and his interactions with others are also presented to provide a deep understanding for which the findings about habits of mind can be contextualized. Connections to the top three habits of mind elements that were identified in Section 4.2.2 will then be discussed based on the details provided in the reflective memo.

This company had a front desk receptionist who I would check in with if they were there, or if not, I would go back to the civil engineer's office on my own. This company had some open offices in the main room and then toward the back there was a hallway that extended left and right and contained individual offices. The civil engineer's office was at the end of one of these hallways. He had a large whiteboard taking up most of one of the walls across from his dual-monitor computers. He kept a bookshelf behind his desk where he frequently reached for different manuals or documents. I would sit on his office chair while he would work at his standing desk while I was there.

Occasionally other employees or the civil engineer's boss would come into his office and would discuss problems or clarify solutions. We primarily stayed in his office during the observations; we rarely visited other colleagues' offices or went into other areas of the company. However, the civil engineer would frequently make phone calls to various stakeholders, the public, or other colleagues to discuss project logistics, solutions, or to clarify information about a project or process. He listened to others' feedback and perspectives about the scope of problems or to verify adherence to standards and specifications. These behaviors that I observed the civil engineer engaging in demonstrated his use of the *Communication* element of the *Interpersonal* habit of mind.

He would review documents that had been edited or produced by another coworker or engineer and would often call them on the phone to discuss the document together.

While discussing, the civil engineer would ask questions to contextualize the document or to verify information that was presented in the document. He would check the document he was reviewing against other, similar documents that had been developed in the past. In these instances, the civil engineer was employing the *Problem finding* element of being *Problem-focused.* He sought to fully understand the scope of a project, determine what actions had already been taken, and generate ideas about what further actions needed to be taken going forward. As he was validating information in the documents he was reviewing with others, he was also employing the *Systems thinking* element of being *Mindful of the bigger picture.* The civil engineer was continually seeking to ensure that he developed a holistic understanding of the problems he was solving. He would frequently reference the standards and specifications manual that he kept in his office cabinet. He recognized that all of their engineering work had to fall within the scope of acceptable standards and specifications for his industry. He was mindful of the fact that he had to account for these standards and specifications at all points during the project cycle.

4.2.3 Electrical Engineer

The third engineer case that was analyzed was the electrical engineer. As described in Section 3.9.2.1, the electrical engineer worked at a small privately held company in the United States. His role was primarily in the design, building, and testing of hardware components that would be installed into the products that his company produced. Table 4-10 provides a count of the number of excerpts that were coded for each individual element within the five habits of mind. This table demonstrates how all five habits of mind are represented in the work of the electrical engineer and how the counts of each of the individual codes were distributed. These counts indicate how different elements were represented in his work and how whether he used them or the frequency in which he used them were dependent on the context of his work.

The following section describes the top three most common codes that were coded in the electrical engineer's data. Representative quotes from the field notes and interview/think-aloud transcripts are provided to highlight instances in which these habits of mind were represented in his work. Section 4.2.3.1 provides a reflective memo written by the researcher that describes the work environment of the electrical engineer during the on-site observations. This memo provides contextualizing information to deepen the understanding of the electrical engineer case. Section 4.2.3.2 then provides the notes that the researcher took during the member-checking session with the electrical engineer. His perspectives and insights on the results of the researcher's analysis are presented in these member-checking notes.

Table 4-11

Within-Case Results from Analysis of the Electrical Engineer's Data.

Habit of mind	**Number of excerpts**	**Definition**
Problem-focused	790	How the engineers engage in the problem solving process, e.g., through investigating, evaluating, or generating solutions to problems
Critical response	25	
Curiosity	152	
Engineering judgement	7	
Informed skepticism	32	
Problem finding	574	
Transparency	0	
Interpersonal	664	How the engineers communicate and work with others
Acknowledgement	3	
Communication	319	
Creative problem-solving	315	
Openness to new ideas	27	
Self-reflective	260	How the engineers reflect on their own actions, maintain personal composure, and express a positive attitude toward learning or problem solving
Adapting	155	
Attitudes	16	
Improving	89	

Managing impulsivity	0	
Mindful of the bigger picture	263	How the engineers approach problems and solutions holistically and consider the broader impacts of their work
Safety	30	
Systems thinking	151	
Visualizing	82	
Technically adept	220	How the engineers use technical tools, such as physical manipulatives, testing setups, or computation tools, during their work
Computation	0	
Manipulation and observation	220	

The most common codes that occurred in the electrical engineer's dataset included *Problem finding*, *Communication*, and *Creative problem-solving*. The analysis of the electrical engineer's data revealed no instances of *Managing impulsivity* or *Computation.*

The code of *Problem finding* was the most common finding from the electrical engineer's dataset. He frequently was engaged in investigating the context of different problems, such as when he was planning out how to conduct tests, and verifying information, such as the results obtained from those tests. During one of the on-site observations, the researcher observed him reviewing test plans for a steering motor.

> "Another engineer comes into the office, and [the electrical engineer] asks him what he observed in the test he conducted. The other engineer says that the actuator light doesn't blink. [The electrical engineer] notes that it will be green when it is activating control, and the engineer asks if it was a problem that it wasn't blinking. [The electrical engineer] says that theoretically on the ACU, there shouldn't be a red light either, but the functionality of this was never fully developed. He says the green light means that the control is enabled and is able to do things, but it doesn't blink."

This instance describes how the electrical engineer was thinking through a problem that was presented to him. He discussed details with another engineer to contextualize the problem they were framing. They described what indicators they were looking for to identify if the test was working as intended. The electrical engineer clarified what should theoretically happen during the test based on what he knew about the system.

The researcher also observed him critically analyzing the information obtained from these types of tests that he conducted. During one of the observation sessions, the electrical engineer made changes to the testing of a motor based on the results he was seeing in real time. The researcher's field notes read,

> "The motor spins intermittently, and changes direction of rotation with each iteration of the test. He attaches some kind of device [not sure what it does - maybe measure current?] that clips onto some of the wires attached to the motor. He adjusts some numbers on the panel of this device. He makes adjustments on the blue machine and the motor starts spinning faster. He presses buttons on this device and will look back and forth between it and the code on the computer screen. He changes something, and the motor starts spinning faster, and for a longer duration than before."

This example demonstrates how the electrical engineer was verifying the information that was being displayed on the computer screen. When he noticed that some of the values were different than what he was expecting, he changed something on the motor and observed the new results as the test was run again.

The researcher also observed him using *Problem finding* when he was verifying the context of a test with another colleague. The field notes stated,

> "[The electrical engineer] mentions something about a 20 Amp, battery and torque test. He's wondering what this means, sets the torque to 50 and increment until there's a [19.9 A] current or there's a failure. They want to measure the battery current vs motor current. He wants to change the wording, specify a torque, and run it a few more times to make it more accurate. He also wants to change the temperature and the duration of the test."

This example shows how the electrical engineer was thinking about the context of the test that he was running and if the procedure was designed to be set to a torque value and then run until failure or until there was a current reading of a specified amperage. He was verifying that for either approach, the information would need to be accurately communicated in the test procedure so that someone else would be able to conduct the test accurately as well.

This engineer also employed the *Communication* element. This code was the second most commonly used code by the electrical engineer. This code was commonly observed because he often worked with colleagues when solving problems and considered their viewpoints in potential solutions. In an interview, he stated,

> "And then oftentimes that is going to go further from there to a few more people to say 'hey, do you feel that this is adequate,' and your ability to take this component and prepare it for use if it's not. What would you add, and then add more information to it at that point."

This quote shows how the electrical engineer interacted with colleagues when generating solutions to problems. He described how he sought the opinions of others to determine whether what he produced was accurate, adequate, or relevant to the proposed problem. He listened to the perspectives of others when thinking about how to improve the solution he generated going forward.

He also demonstrated the *Communication* code when needing to communicate his own ideas clearly and confidently to others. In one instance, he described how he made an effort to explain to fellow employees why certain processes were the way that they were. When interviewed about this, he described,

> "And even for me, having it in front of me makes a difference and it's helpful, especially when trying to explain to somebody why they're seeing what they're seeing at certain stages. Like when the operator comes back and says, "Hey I did this, I ran the test on it, but the test failed." To be able to explain that and say, "Well yes and this is why." Rather than just say, "Yeah." You know, it's helpful. I like to communicate that, whether people are interested in it or not, sometimes, just so that they just understand."

This example highlights how the electrical engineer valued actively communicating with fellow employees, such as machine operators, so they would be able to clearly understand why a certain process or test procedure was written in a certain way. He wanted others to learn about these processes rather than only telling them what to do.

The electrical engineer also emphasized that having *Communication* skills was essential to his job as an engineer and argued that it was important for many others' engineering jobs. He described,

> "Yeah, being able to effectively communicate particularly when there is problems, which is a large portion of my job, and a large portion of a lot of engineers' jobs. Being able to communicate problems effectively, so that I guess, either safety issues or potentially, potential problems are kept within the scope that they are in, rather than get misconstrued or drawn out into something a lot scarier than they might in reality be. So being able to effectively communicate that, and also being able to effectively communicate with other people to make sure that you can actually work together to solve a goal and not be duplicating work or in some cases, sort of fighting against each other, without even knowing, is an important thing to be able to communicate to avoid those things."

This quote illustrates how important the *Communication* code was to the electrical engineer. He believed that being able to effectively communicate with others was critical to being able to solve a common goal and establish clarity on the direction of their work in the present or the future.

The third most common code present in the electrical engineer's data was *Creative problem-solving.* This code was defined for this study as "applying techniques from other traditions, generating ideas and solutions with others, generous but rigorous critiquing, and seeing engineering as a 'team sport'" (Lucas & Hanson, 2016, p. 6). This engineer often worked with colleagues to generate ideas about solutions to problems and to troubleshoot different issues that occurred. He commented on the importance of working with others and leveraging others' expertise in certain areas. In one example, he described how it was important to get feedback from stakeholders or other employees that would be using the documents that he created. He said,

> "That's one of the things that is, I guess, one of the most critical things that I think because, especially because I've been on both sides of it, is to make sure that after documents are created or whatever else, that the loop is closed by feedback from

> the people who use the document, to make sure that you're not inferring or making assumptions that somebody might understand that's using that document. That they let you know, "Hey, it didn't tell me to do this." And you're like, "Oh, well yeah I didn't write that in there because I just knew that. But it needs to be in there so thank you." And so, you know, you make those changes so that the person that's expected to do that work that the document is written based on their level of knowledge."

This quote shows how the electrical engineer valued getting feedback from the operators that were using the documents he generated, because they provided perspectives on areas that the electrical engineer might not have considered, such as whether instructions were clear or not.

Three codes were not identified in the electrical engineer's data, including *Managing impulsivity, Transparency,* and *Computation.* There were no identified instances of the electrical engineer employing the element of *Managing impulsivity,* but this does not indicate that he did not act thoughtfully or deliberately. The analysis of his data did not reveal instances of this particular code explicitly. Additionally, the analysis of his data revealed no instances of him enacting *Transparency*. This does not indicate that he did not act in a *Transparent* manner, but that during the times of the observations, he was not observed to be enacting that element specifically. Similarly, the analysis revealed no instances of the *Computation* code. The electrical engineer was not observed using a calculator or performing calculations or computations for his job. He would often read and evaluated test results, which may have outputted numbers in some instances, but he was not personally manipulating these numbers in order to solve a particular problem.

4.2.3.1 Electrical Engineer Reflective Memo

Reflecting on the experience of conducting the on-site observations with the electrical engineer helped provide insights about the context of his work environment and how habits of mind were represented in his work accordingly. Reflecting on the electrical engineer's work environment provided insights about what the physical work space looked like and how that informed the context of his work. Reflecting on the types of activities the electrical engineer engaged in on a day-to-day basis provided more information about how habits of mind were represented in his unique work role. Connections to the top three elements of the broader five habits of mind (as described in Section 4.2.3) will then be discussed based on the activities detailed in the memo.

This company had a front desk receptionist and a tablet on which visitors would sign in each time they visited. I would input my name and my affiliation (Utah State University) and it would notify the electrical engineer by email that I was visiting. This system would also print out a sticker visitor name-tag that the front desk attendant would give to me and I'd wear for the duration of each observation. The front area of this company had open office space with many people interacting and moving around. Along the back wall of this company was a door leading onto the production/shop floor where there were numerous products, testing suites, and mechanical systems. This is where I would conduct the observations with the electrical engineer.

The electrical engineer had two different office locations during the time I observed him. His first office was in a small room located in the shop floor area of the company. This room had open desks for each person that worked there. His desk here had a dual-monitor computer set up that he would also attach his laptop to and use that as a third monitor. He had many objects on his desk that related to his job, like wires, cables, tools, and circuit components. He also had a set of drawers beneath his desk that contained different items that he would use as well. I would sit in an unoccupied desk chair when I observed him in this room.

The second office location that he worked at was in another room on the shop floor that had a glass wall separating it from the shop floor. There were also multiple open desks here in this room and a large whiteboard on one of the walls. There was a large TV monitor on the wall opposite the whiteboard that was used during meetings that were held in this room. There was also a large table in the center of this room where employees would sit during these meetings. During the observations with him in this room, I would sit in one of the unoccupied chairs from the conference table.

The electrical engineer performed work on his computer, such as revising and updating test plan documents or instructions, reading set-up and installation instructions for products he was working with, or creating and updating schematics of electrical components using the appropriate software. These types of work activities demonstrated how the electrical engineer used the *Problem finding* element of the *Problem-focused* habit of mind. He would familiarize himself with the electrical components he was manipulating by reading the set-up and installation instructions. This provided him with contextualizing information about how the products were intended to be used and their overall functionality. He would also investigate schematics of electrical components to determine whether there were any errors when the schematic was run or if the features of the schematic reflected the physical components.

The electrical engineer most often performed work that involved being out on the shop floor interacting with other engineers or technicians, setting up physical testing units by wiring different components and verifying the testing procedures, or physically interfacing with one of their products to ensure the components were working as intended. His work with other engineers or technicians demonstrated that he used the *Communication* and *Creative problem-solving* elements of being *Interpersonal.* He leveraged the expertise of fellow engineers to work together to troubleshoot errors with the interface between software and hardware components. He also listened to the perspectives of other engineers or technicians who performed some of the testing in order to make the test procedures easier to understand and follow. These types of activities drove most of the electrical engineer's work when I observed him.

4.2.3.2 Member Check with the Electrical Engineer

The member checking session with the electrical engineer was conducted virtually using the Zoom platform. Prior to the member checking session, the researcher emailed the electrical engineer a summary of the findings from the analysis of his data along with descriptions of the five overall habits of mind that were generated from the analysis. The engineer was provided with a count of the number of excerpts associated with each code that was present in his data and a summary of the top three most common codes based on the counts. A sample of the member checking questions that were used during the session are presented in APPENDIX B.

During the session, the electrical engineer indicated that he agreed with the researcher's grouping of the codes into the broader habits of mind. He commented that *Managing impulsivity* could have been grouped in *Interpersonal* rather than *Self-reflective,* but that he thought it was suitable to be in *Self-reflective* as the researcher had grouped it. He also agreed with the researcher's labels and definitions of the habits of mind. The electrical engineer did note that he felt that the *Interpersonal* habit also had a component of maintaining tactfulness when interacting and communicating with others. He commented that it was important to be mindful when receiving constructive criticism from colleagues or management and to not "take for granted" what others may consider when solving problems. He said that it was important to him to respond to constructive criticism with tact and to not take offense when others may disagree or offer other insights on his work. He commented that engineers are not typically taught how to receive constructive criticism and that this aspect of communication was important to him.

The electrical engineer also said that he felt that being both *Interpersonal* and *Self-reflective* were important to communication and interaction with others. He said that he thought it was important for these habits of mind to be separate though, because they both considered specific components that made them unique.

When asked about whether he agreed with the summary of his overall work based on his top three most common codes, he agreed that the summary that the researcher provided was accurate. He commented that troubleshooting and investigating problems was a natural part of his work. The electrical engineer also noted that he was always receiving and relaying information as part of his job, highlighting that these communication abilities were extremely important and beneficial to his work and the overall goals of the company. He commented that "if you can't communicate, your gifts are lost" and that "people won't be able to receive the benefits of your work."

The electrical engineer also commented on the counts of the number of excerpts that were coded for each code that was present in his data. The codes for *Managing impulsivity*, *Computation*, and *Transparency* had zero instances in his data. For

Managing impulsivity and *Transparency* in particular, he commented that this was likely due to the researcher not happening to observe him enacting those habits of mind on the particular dates and times of the observations. He said that he may have used those codes in his work but recognized that they might not have been captured in the field notes from the observations or during the interview/think-aloud sessions.

For the *Computation* code, the electrical engineer said that it seemed reasonable to him that there were zero instances of this code in his data. He indicated that his work role and focus during the time of the observations and the interview/think-aloud sessions did not require him to perform computations. He noted that he was working more with analyzing and interpreting datasets and results from datasets rather than calculating or manipulating new data.

Last, the electrical engineer commented that he thought it was reasonable that some of the elements that were coded in his data appeared less than others. He said that he thought the thematic groupings of the codes into broad habits of mind provided validation for why some of the codes were less frequent than others. For example, he said that he appreciated that the code of *Managing impulsivity*, which had zero coded instances, was grouped with other codes under the *Self-reflective* habit that elements with much higher instances, such as *Adapting* (155 instances) and *Improving* (89 instances). He expressed similar sentiments for *Transparency* (0 instances) being grouped into *Problem-focused*, which contained higher-coded items such as *Problem finding* (574 instances) and *Curiosity* (152 instances). He commented that because the groupings contained codes with both higher and lower counts, the groupings were less “skewed,” that the habits "rounded each other out," and that the use of the habits would "wax and wane with each other" depending on the work being performed.

4.2.4 Biological Engineer

The fourth and final engineer case that was considered for this study was the biological engineer. As described in Section 3.9.2.2, the biological engineer worked at an employee-owned, international company in which she served a role exploring biological processes and applications. Table 4-12 provides results from the within-case analysis from the biological engineer's data. This table shows counts of the number of excerpts that were coded for each of the five habits of mind and the individual elements that comprise them. The results in this table demonstrate that all five habits of mind and their components were present in the work of the biological engineer. The differing counts across the individual elements suggest that the ways in which these habits were represented in the biological engineer's work were dependent on her job and workplace context.

The following section outlines the top three most common codes that were coded in the biological engineer's data. Representative quotes for each of these codes are presented to illustrate how they are represented in her work. Section 4.2.4.1 provides a reflective memo written by the researcher to provide contextualizing details about the biological engineer's work environment when the observations and interviews were conducted with her. These details help provide deeper insights into the nature of the biological engineer case and strengthen the findings obtained from the case analysis. Section 4.2.4.2 then provides the notes that the researcher took during the member-checking session with the biological engineer. Her perspectives and comments on the results from the analysis of her data are presented in these notes from the member-checking session.

Table 4-12

Within-Case Results from Analysis of the Biological Engineer's Data.

Habit of mind	**Number of excerpts**	**Definition**
Problem-focused	1957	How the engineers engage in the problem solving process, e.g., through investigating, evaluating, or generating solutions to problems
Critical response	214	
Curiosity	196	
Engineering judgement	9	
Informed skepticism	318	
Problem finding	1140	
Transparency	80	
Interpersonal	1424	How the engineers communicate and work with others
Acknowledgement	31	
Communication	711	
Creative problem-solving	596	
Openness to new ideas	86	
Self-reflective	215	How the engineers reflect on their own actions, maintain personal composure, and express a positive attitude toward learning or problem solving
Adapting	128	
Attitudes	16	
Improving	67	

Managing impulsivity	4	
Mindful of the bigger picture	588	How the engineers approach problems and solutions holistically and consider the broader impacts of their work
Safety	6	
Systems thinking	495	
Visualizing	87	
Technically adept	155	How the engineers use technical tools, such as physical manipulatives, testing setups, or computation tools, during their work
Computation	113	
Manipulation and observation	42	

The researcher found evidence of the biological engineer employing all of the elements within the five identified habits of mind. The most common coded elements that occurred in the chemical engineer's dataset included *Problem finding, Communication,* and *Creative problem-solving*.

The first most common code employed by the biological engineer was *Problem finding.* The biological engineer used *Problem finding* when she determined the types of products to propose to a client, when she analyzed and interpreted on-site field data obtained from the products, and when she worked with colleagues to determine problem scopes. During one of the observations, the researcher observed the biological engineer analyzing and interpreting data that was generated from one of her company's products that was being tested in the field. When interviewed about this analysis process, the biological engineer indicated that she was looking for "anomalies" in the data that suggested that the product was not performing as they anticipated. She stated,

> "So that's kind of where we saw similar trends. But there were some anomalies. And that was another reason I thought maybe we had some sample valve issues, is those anomalies suggested to me that there was like some sort of delay or there was a mixing for a while of the samples. So we weren't getting really clear, even if the trends were similar. The numbers weren't. So precision was not high, but accuracy and trends seemed to be high. So we were confident that the trends were happening, we just weren't confident on the exact values."

This example demonstrates how the biological engineer used *Problem finding* to investigate the data that she was analyzing and determine its accuracy and potential points of inaccuracy. She indicated that she was able to determine through this process that there were trends present in the data but the values were not able to be determined.

This insight allowed her to determine that there were "anomalies" in the data and could provide a suggested route for her and her colleagues to pursue to solve the problem.

The biological engineer also demonstrated the code of *Communication.* She described the importance of being able to communicate information to a technical and non-technical audience to ensure that all relevant stakeholders to a project would understand it and its goals. She noted how it was important to be able to communicate with those who would be using the engineered products out in the field and may not have as thorough of a technical background as a fellow engineer. During an interview, she said,

> "It's one thing to build and install, it's a whole different thing to operate a lot of these equipments. So then we have to be able to communicate to operators who typically are like high school level of education. There's some real sophisticated operators, but a lot of them also in small towns are like the town lawnmower and things. So being able to translate complex operational principles to somebody who's got to push all the buttons and pull all the levers is another aspect of communication."

This quote demonstrates the importance that the biological engineer placed on being able to effectively communicate with non-technical audiences that would have to physically operate the products her company produced. She further highlighted this idea when describing how this aspect of *Communication* was also relevant when communicating information to project managers who may also not have a background in engineering. She described,

> "Especially where in our role, we take an engineered concept and we fabricate something out of it. So the engineers who do all the nitty-gritty calculations then have to transfer that to project managers who often don't have an engineering background. Of if they do, bachelor level, to be able to actually produce it. So there's a lot that has to transfer between the guys who are really technically savvy and the guys who actually have to build and fabricate and put it in the field. So that communication is probably the most that [company] does is internal to get [inaudible] to fabricators, to get a project or a product actually made."

This example further supports the biological engineer's perspective on the importance of being able to communicate with a variety of audience. She also commented that, "You might have done the best job in the world but if you can't communicate its value it doesn't go anywhere." These examples show the importance that *Communication* played in the biological engineer's work and within her company at large. The results from her data suggest that effective communication was essential to being able to work with others and deliver products effectively to the intended consumers.

The third most common code found in this engineer's data was *Creative problem-solving.* This code was represented frequently in the biological engineer's data and was typically characterized through her working with others to solve problems, generate solutions, or evaluating data and results. During one of the observation sessions, the researcher sat in on a group meeting that the biological engineer was participating in. She and her colleagues were discussing their plans for designing and building a product for a client. During this meeting, the group was asking each other questions, clarifying information about the scope of the project and its needs, and determining potential solutions. A portion of the researcher's field notes from this observation session read,

> "[The biological engineer] asks someone directly, "What have you seen for sludge transfer?" The group talks about this. [The biological engineer] says that "we have it as 22 feet in the tank diameter in our scope. That should give you about 30 days of sludge storage. It's recommended to keep the tank half full in case there is a loss of biology, which can help reduce startup times." The group talks about this."

This example from the field notes highlights an instance where the biological engineer was using the element of *Creative problem-solving* to contextualize information about a project she and her colleagues were working on. She asked others in the group their perspectives and what they had seen previously to help inform the decision-making process. *Creative problem-solving* was also apparent in the biological engineers' data through her descriptions of the peer review process. She indicated the importance of having others checking over her work that she had done. She described in an interview,

> "We've got a place where we always kind of sign who worked on it last. And that's also required for audit is that you have to do ... Always have it checked by somebody. So who ran the program and who checked the program. And that's required by our quality council, that there's always a second set of eyes to make sure that nothing broke."

This quote shows how it was important to the biological engineer to have her work reviewed by someone else to ensure that it met their standards of quality. She reflected this same perspective during another interview in which she stated,

> "I had done the calculations to look at what general flow range we think we will be in. But I saved an email to myself because I wanted to double check it with my supervisor before I sent it out just to make sure we didn't contradict ourselves on any earlier calculations we'd given them."

This example also indicates how the biological engineer wanted to validate the work that she did with another person on her team or within her company. This is reflected through the *Creative problem-solving* code because it represents how the biological worked with others to solve problems, generate ideas, and evaluate information.

4.2.4.1 Biological Engineer Reflective Memo

The reflection about the observations that I conducted with the biological engineer described in this reflective memo provides contextualizing information about the types of work that she did on a day-to-day basis at her workplace. This reflective memo also provides insight into how she interacted and worked with others in a virtual, online space. Both types of details provide a more robust understanding of the nature of the biological engineer's work and how the habits of mind that she used were represented in her unique contextual environment. This memo first describes the nature of the physical and virtual spaces in which the biological engineer worked. This memo then discusses some of the specific work activities that she engaged in on a daily basis. Connections to the top three habits of mind elements that were described in Section 4.2.4 are also presented.

Out of the 12 observations with the biological engineer, two of them were in-person and 10 of them were conducted virtually over Zoom due to the COVID-19 global pandemic. The two in-person observations were conducted at her company's local site location. She did not have a dedicated office space here; we reserved a conference room and she performed her work on her laptop on the conference room table. During these observations, I sat in an unoccupied chair at the conference room table. For the remaining 10 observations, she performed her work at the company's primary location where she had her own individual office cubicle. These two-hour observations were conducted over Zoom where she would share her laptop screen unmuted with me so I could see what she was working on as well as hear any conversations with colleagues she had or phone calls that she made.

The biological engineer performed work on her own as well as with other colleagues. She would work independently to review calculations in Excel programs that performed computations, reviewed documents prepared by colleagues, and developed presentations. The biological engineer also attended virtual meetings and had phone calls using Microsoft Teams, where she and her colleagues would discuss and review project documentation, budgets, and to make design decisions about their company's products. During these group discussions, the elements of *Communication* and *Creative problem-solving* within the *Interpersonal* habit of mind were represented. She and her colleagues generated ideas together about which particular design was best for their target customer. They also worked together to review budgets and work proposals to ensure that the information captured was accurate.

Similarly, she sought others' insights when she was working on a project. She would call them on Teams to discuss the scope, needs, and progression of projects. She communicated with other team members and employees outside of her immediate team to get an understanding of the context of the project she was working on and its requirements (*Problem finding*). She used what she learned in her discussions with others to refine her thinking of her own work and better communicate her needs or updates to her team (*Communication*).

4.2.4.2 Member Check with the Biological Engineer

The member checking session with the biological engineer was conducted virtually using the Zoom platform. Prior to the member checking session, the researcher emailed the biological engineer a summary of the findings from the analysis of her data along with descriptions of the five overall habits of mind. A count of the number of excerpts associated with each code that was present in her data and a summary of the top three most common codes was also presented. A sample of the member checking questions that were used during the session is presented in APPENDIX B.

Before the researcher asked any formal questions, the biological engineer commented that viewing the summary of her findings was "introspective." She said that she appreciated the opportunity to see an outside perspective of what her day-to-day workplace activities looked like. She commented that she noticed that one element of the habits of mind that she wanted to consider more was *Safety*. The researcher described that during the analysis of the biological engineer's data, evidence of *Safety* was frequently represented when the biological engineer described how their processes needed to be designed to ensure that certain environmental quality standards were met, specifically regarding drinking water. The biological engineer indicated that she agreed with this interpretation of *Safety*. She commented that she wanted to improve her consideration of *Safety* to include the physical construction and implementation of her company's products. She described how the engineering group can generate "an elegant engineering design," but that they also need to consider if it is "safe to operate and install." She said that it was important to "know the needs of the contractors" that would be physically handling the process units that were being installed. In this example, the biological engineer indicated that they would consider adding "lifting handles" to support the operators and technicians that would be installing components of their products on-site.

The dissertation researcher then asked the biological engineer for her impressions of the description of her work based on the top three elements that were coded in her data. The biological engineer indicated that she agreed with the description of her work that the researcher generated based on the analysis of her data. She described that a portion of her work during the time of the observations had an emphasis on the sales of her company's products. She said that in this role, it was important in her work for her to understand both the needs for production and the needs of the people who would be physically doing the production.

Following this thought, the biological engineer also commented that when reading the summary of her findings, she was curious about how an engineer's role would influence their habits of mind. She described how for her sales role, she was communicating both externally to non-technical audiences or engineers in different disciplines. She also said that she was responsible for communicating internally with other members of her team that were familiar with their company's processes and procedures. She described how this role required her to be able to speak "a different language" and "use different mediums" for communication that would dominate when interacting with one audience over another. She also commented that for the *Interpersonal* habit of mind, it was important to her that there were "different knowledge bases represented in a room" and that to effectively solve a problem, they "need everybody to give a little input."

The researcher then asked for the biological engineer's perspectives on the groupings of the codes into five broad habits of mind. The biological engineer said that she felt the grouping of the codes represented the five habits of mind well. When looking at which codes were grouped into each of the five habits, the biological engineer commented that she wondered whether these habits were represented when working on unique tasks or if they were more broadly represented across the scope of an engineer's work. The biological engineer discussed how different parts of her job required her to be in "one mode or another" when it came to whether she exhibited certain habits of mind or not.

The biological engineer then described how she felt the element of *Engineering judgement* was important to consider in engineering practice. She described how in undergraduate engineering education, students typically follow "protocols and procedures that are well understood and clearly defined." She contrasted this to say that "in the real world," engineers are often presented with "a new problem" that does not have any "literature or textbook references to guide" the design of a solution. She said that these instances are where *Engineering judgement* is crucial, because "you have done it one way before" and know from experience that something works. She said that this type of thinking can be "uncomfortable" for engineers that are used to following strict rules and procedures. The biological engineer described how in the discipline of biological engineering, she had to recognize that "biology is inherently unpredictable." She said that she could make a lot of macro-observations about how processes were performing, but the manipulation of the actual biology was a difficult process. She said that manipulating biological processes has "less defined inputs" and that "it comes down to a judgement call" by the engineer to decide what a solution should look like based on their professional experience. She said that there "is no equation to fit what you need" in that type of situation.

Last, the biological engineer commented that she was reflecting on how these habits of mind could influence engineering students in the classroom. She said she was thinking about "how much can be taught versus how much is innate." She said thought it was important to "make students of aware of what to expect" in engineering, and allowing them to "find a role that fits their strengths." She thought that sometimes, there may be too much of an effort to "fix people's weaknesses" rather than "highlight their strengths." She commented that one way to approach teaching habits of mind in engineering education may be to give students an opportunity to find "where their strengths can be highlighted" and guide them to engineering roles that would allow them to showcase these strengths.

4.3 Cross-Case Analysis

The previous section described each engineer case in detail, including which codes and habits of mind were present within the analysis of each case. The following sections will describe the cross-case analysis, where the major identified codes and habits were compared and contrasted among the four engineer cases and their respective contexts. Codes or habits that were not represented in any of the four engineers' data are also described and discussed.

4.3.1 Habit of Mind 1: Problem Solving

The cross-case analysis revealed that all four engineer cases employed the *Problem finding* code. Furthermore, *Problem finding* was the most common code present in all four engineers' data. The second cycle of coding grouped this code into the *Problem-focused* habit of mind. All of the engineers employed different characteristics of the habit of being *Problem-focused* depending on the situation in which they were working.

For example, the civil engineer often analyzed and interpreted construction plans and map plans in accordance with the relevant state standards and specifications. He investigated the contexts of proposed construction plans and validated them with the appropriate state standards for the construction. He also remained critical of information that he was reviewing regarding proposed construction plans, map plans, or demolition plans. He critically evaluated the claims that were made about adherence to standards and specifications and verified this information himself as he was reviewing them. He ensured that anything that he stamped with his signature was of high quality and contained credible information.

The chemical engineer analyzed data and made projections and forecasts to improve efficiency, meeting budgetary goals, and uphold the morale of the production workers. She asked questions about why certain data looked the way it did and remained critical about the source of data. She was committed to always operating from “the source of truth” and questioned where information came from before she made decisions based off of it. When relaying information to others, she remained open and honest about how she computed values, where the data that she used came from, and demonstrated evidence about the credibility of the data that she used.

The electrical engineer explored ways to physically build and wire electrical systems so that he could then perform tests using them. He disassembled products that he would be using to determine how they worked and investigate their functionality and capabilities. He tested different wiring setups to determine sources of error or troubleshoot any malfunctions. He appreciated the perspectives that were given to him by others about how to solve a problem, but also remained critical of these perspectives to ensure that correct information was being implemented into a solution. He critically evaluated sources when seeking information before integrating these ideas into his work.

The biological engineer evaluated quantitative data from her company’s biological products and compared it to information she observed when she would physically go on-site to their products in the field. She remained critical of information that she was reviewing by comparing it to what she had observed before from previous tests. She used her prior experiences to inform her judgements about where errors appeared in data and what may have caused them. She also remained open and upfront with potential customers about the types of products they could offer to them and the expectations for the level of work, maintenance, and involvement that they would have if the company chose to do business with them.

4.3.2 Habit of Mind 2: Interpersonal

Additionally, the cross-case analysis revealed that all four engineers used the code of *Communication.* The analysis of all four engineer cases revealed that this habit of mind was one of the top three most found codes across all four cases. The second cycle of coding grouped this code into the *Interpersonal* habit of mind. All four engineers employed this habit of mind in some way or combination of ways in order to be successful at their job. Being *Interpersonal* was essential to how the engineers communicated and interacted with others at the workplace. For example, the chemical engineer frequently worked with the line operators who were responsible for managing the processes that she designed to improve production and efficiency on those lines. She emphasized how it was important to her that she took the line operators' perspectives into consideration when she was working on new processes for them to implement. She wanted everyone on the team to agree to the plans going forward and wanted to ensure that the ideas she had would be useful for the operators in practice.

The electrical engineer employed the *Interpersonal* habit of mind in a similar way, in that he sought to solve problems with other engineers or technicians to obtain their perspectives and insights. In the interviews, he commented on the importance of being detailed enough when writing test plans so that the technician using it would be able to successfully complete the task. This process involved him communicating with the technician to determine the types of information that they looked for when reading test plans or manuals. These interactions allowed the electrical engineer to be open to perspectives that he may not have considered, since he approached writing the test plan with his own preconceived knowledge about the process.

The biological engineer also employed the *Interpersonal* habit of mind through her work as she frequently attended team meetings and phone calls. She worked with others to define problem scopes, write proposals for their work, and evaluate data obtained from field tests. She would ask her coworkers for their insights on various projects and use those insights to inform her work going forward. She also worked with others when she evaluated and analyzed data. It was a team effort for her and her colleagues to identify anomalies in data and determine how to rectify those issues.

Last, the civil engineer demonstrated the *Interpersonal* habit of mind through his frequent interactions with other engineers, project stakeholders, and the public. Due to the nature of his job, the civil engineer mediated interactions between the engineers working at his company and the political landscape in the community in which he worked. The ability to be *Interpersonal* was crucial to ensuring that ideas were communicated effectively, intentionally, and respectfully. This was also an important habit of mind for him to maintain as he listened to the perspectives of these stakeholders and incorporated their feedback into his design solutions. The civil engineer commented on these interactions, describing how sometimes he made decisions based on "political will" versus technical engineering rationale. He indicated that these solutions were no less effective, but the ultimate choice was made based on a stakeholder's input rather than empirical evidence.

These examples all explored how the engineers used the habit of mind of remaining *Interpersonal*. This habit was present across all four engineer cases, but the specifics of how it was represented in each case depended on the case context. Overall, the *Interpersonal* habit of mind was important to the work of the engineer cases and demonstrates how effectively working and interacting with others is central to the engineers' work.

4.3.3 Habit of Mind 3: Self-Reflective

The ability to be *Self-reflective* was also present in the data from all four engineer cases. This habit of mind described how the engineers were reflective of their decisions and actions, how they maintained personal composure and thoughtfully considered solutions, and the ways in which they expressed a positive attitude toward learning and toward the field of engineering in general. The four engineer cases all demonstrated evidence of this habit of mind in different ways.

The chemical engineer used elements of the *Self-reflective* habit of mind when she reflected on data about the effectiveness or efficiency of processes that she implemented in her company. She also reflected on previous decisions that she had made regarding these processes and evaluated whether they were successful or not. She used these ideas to make decisions going forward about how to improve or change these processes. The chemical engineer also employed the ability to be *Self-reflective* when she reflected on the perspectives that were given to her by her colleagues or line operators. She evaluated their perspectives on the processes and procedures that she implemented and used these perspectives to guide her in improving these processes.

The civil engineer employed the *Self-reflective* habit when he described how he enjoyed his job. He expressed positive attitudes about his career choice and his particular job role at his company. He reflected on the fact that some days it was challenging and demanding but he acknowledged that these feelings contributed to his enjoyment of his profession. The civil engineer also maintained the ability to be *Self-reflective* when he described how he was always aiming to keep their document templates and processes up to date to ensure that they are always improving these processes. He said that he always “tries to optimize what we do,” and that he felt that he was not “content with just leaving things as they are.” He recognized that it was important to be open to reflecting on the effectiveness of processes in the present and determining how they can be improved going forward.

The electrical engineer employed the *Self-reflective* habit of mind when he analyzed and interpreted the results of tests. He frequently tested the functionality of different programs or components and made decisions about how to improve it going forward. He also used the *Self-reflective* habit when he discussed how he made changes to test procedures or plans based on feedback from the technicians or operators that would be using them. He recognized that these groups of people had a different set of skills and knowledge than he did as an engineer, and as a result, there were certain things in the test procedure that they felt were unclear or confusing. He maintained the *Self-reflective* habit of mind to recognize that he would have to write test procedures with the end user in mind and consider their needs in addition to what he felt was essential to the document.

The biological engineer demonstrated evidence of the *Self-reflective* habit of mind when she reflected on the performance of the products that her company developed. She would reflect on the types of processes and procedures that she and her company had used before and used these ideas when generating solutions to improve their products in the future. She would also propose new ideas to her colleagues based on ideas that she had for improvements to their designs. The biological engineer also used the *Self-reflective* habit of mind when she reflected on perspectives from her company's customers. She used customer feedback about their desired components and solution methods when designing products for them. She was able to reflect on these insights and remain open to integrating them into the solution to improve it.

4.3.4 Habit of Mind 4: Mindful of the Bigger Picture

Mindful of the bigger picture was the fourth habit of mind that was identified in all four of the engineer cases in this study. This habit described how the engineers approached problems as holistic systems that were comprised of many complexly interrelated parts and how they considered the broader impacts of their work on society.

The chemical engineer demonstrated being *Mindful of the bigger picture* when she was determining areas of improvement for the production lines at her company. When evaluating areas of improvement, she would consider where sources of error were being introduced into the process. These sources could have included human error, machinery malfunction, or miscommunications amongst operators, technicians, or engineers. The chemical engineer had to consider all of these factors when she was evaluating processes and making decisions about how to improve them. She also needed to be *Mindful of the bigger picture* when forecasting the amount of product her company produce. She had to consider their customers' timeframes for receiving the finished product, the budgetary constraints, the physical limitations of production within the plant, and the level of staffing that would be required to deliver the product. The chemical engineer had to consider previous data that they had obtained to predict the metrics that she would use to schedule the production of new products.

The civil engineer showed evidence of being *Mindful of the bigger picture* by frequently employing a *Systems thinking* perspective. He often had to consider multiple different aspects of projects, including the materials used for construction, the site location of a construction, the quality of the soil at the site, and the safety implications of the surrounding community. To design an effective construction plan, the civil engineer had to think about the bigger picture related to the project and all of the related aspects.

The electrical engineer used the *Mindful of the bigger picture* habit when he was considering multiple factors that comprised his company's products. When writing procedures and conducting tests, he considered the timing of the test, the torque output, and the amperage required. He would also take temperature measurements during these tests to determine if the values were as he expected. The electrical engineer also participated in safety reviews with his colleagues where they generated ideas about potential hazards of their products and how these hazards would be mitigated. He indicated that this was an important part of the design process and would demonstrate to their customers that their products were tested and evaluated for safety. These processes demonstrate how the electrical engineer was able to see the broader impacts of the products his company designed and considered not only a variety of technical components but also careful safety considerations.

Last, the biological engineer used the habit of being *Mindful of the bigger picture* when she was considering the many components within her company's products. She often had to consider the biology that was used in their products and its properties along with the physical construction and design of the product, including the materials it was built from, its shape, and the location of certain components within it. This required the biological engineer to be *Mindful the bigger picture* and account for the biological, mechanical, and electrical components that contributed to its functions. She was also mindful of the safety factors associated with the products. To treat water, for example, the biological engineer had to account for environmental regulations that prohibited certain levels of contaminants if the water was to be used for drinking. When designing systems, she had to ensure that the biology within their products would effectively treat and remove the contaminants in the water to allow it to be safe for people to drink.

4.3.5 Habit of Mind 5: Technically Adept

The fifth and final habit of mind that was present in the data from all four engineer cases was the ability for them to be *Technically adept.* This habit of mind consisted of how the engineers used physical manipulatives, testing setups, and computation tools to solve problems.

The chemical engineer used the *Technically adept* habit when she performed computations in spreadsheets. She would manipulate and perform calculations on data that she obtained from the output of the production lines at her company. This ability to be *Technically adept* allowed her to make decisions about forecasting, scheduling, and determining sources of inefficiency within the production process so that she could develop solutions for them.

The *Technically adept* habit of mind was also represented in the work of the civil engineer. He used physical manipulatives, such as scales, when calculating values that were pertinent to a map plan. He also would occasionally go to site locations where there were proposed constructions or demolitions to take measurements, evaluate the condition of the site, or to take photographs of the location. He used these skills to make informed decisions about how to design map or building plans, how to write procedures for a demolition, or to convey information to relevant stakeholders.

The electrical engineer demonstrated evidence of being *Technically adept* when he was conducting and establishing physical tests of the products his company produced. He would frequently build and wire electrical systems that he would then physically test on the production floor. The electrical engineer would also troubleshoot physical systems by taking them apart to determine how they operated or to learn more about the system he was investigating.

Last, the biological engineer demonstrated evidence of being *Technically adept* when she performed field work on-site with her company's products. She would disassemble portions of the products on-site to determine how well the biology was working or to troubleshoot errors that were appearing in the output data from the products. She used observational evidence in conjunction with quantitative evidence to evaluate if the products were performing as they intended. These physical and observational skills that comprised the *Technically adept* habit of mind were important for her to be able to identify sources of concern and determine how to address them.

4.3.6 Elements of the Five Habits of Mind That Were Not Represented Across All Cases

The cross-case analysis also revealed that several elements within the five habits of mind were not found in certain engineers' data. First, the civil and electrical engineers did not use the code of *Managing impulsivity*, while the chemical engineer and biological engineer did. The civil engineer and the electrical engineer demonstrated no instances of this code, but that does not indicate they were not acting with thoughtfulness or deliberation. The analysis of their data revealed no particular instances where this code was made apparent. During the member checking session with the electrical engineer (Section 4.2.3.2), he suggested that the researcher may not have observed him explicitly enacting this element on the day that he was observed. He agreed that this result did not suggest that he never used this element, but that it was not observed by the researcher on the particular days and times of the researcher's observations. In contrast, the analysis of the chemical engineer's data revealed that she openly acknowledged several instances where she was managing her emotions and thoughtfully responding to a situation rather than acting on impulse. This is likely due to her role within her company, which she described as "social engineering." The analysis of her data revealed many instances where she described the importance of being sensitive and open to the perspectives, ideas, and opinions of others within her company, even when their ideas may not be correct or align with her personal beliefs.

The data from the biological engineer also revealed that she took time to deliberate on problem solutions and contexts before making a decision, particularly during reviews of the legal components of the projects. She described how she would work closely with Non-Disclosure Agreements (NDAs) when entering partnerships with new companies and how it required her to be thoughtful about the kind of information that would be shared outward from her company. She also was involved in the patent process for her company's products and worked closely to ensure that their designs were not infringing on any existing patents. Both of these examples demonstrate how the biological engineer was able to *Manage impulsivity* and thoroughly contemplate the different factors that were involved in generating solutions and working with external companies. Had she acted on impulse, small and important details may not have been carefully considered and could have negative effects on her company's reputation long-term.

The second element within the five habits of mind that was not present across all four cases was *Manipulation and observation*. The chemical engineer did not employ this element, but the civil, biological, and electrical engineers all did. This was likely due to the nature of the chemical engineer's job as described in this engineer's within-case analysis (Section 4.2.1.1). Her job role did not require to her personally observe production lines on the plant floor or to use physical manipulatives to solve problems with the production lines. Her role was focused on the management of those production lines, including their efficiency, scheduling, and the personnel operation them. In contrast, the electrical engineer and the civil engineer both were observed using physical manipulatives to help them solve problems. The electrical engineer was responsible for designing, constructing, and testing physical components that went into their company's products, such as motors. The civil engineer was observed in one instance using a scaling tool to help him identify locations and distances that he then marked on a physical printout of a map plan document. The biological engineer performed *Manipulation and observation* when she visited her company's products on-site where she would observe their performance, adjust, and evaluate the processes that were occurring.

The third element that was not present across all four of the engineer cases was *Computation.* All four engineers employed this element except for the electrical engineer. The electrical engineer's work primarily focused on developing and validating tests of hardware components. He did not demonstrate instances of computing values or manipulating data to solve problems. He would run tests to collect data and evaluate their consistency with previous tests but would not perform computations on this data. During the member check session with the electrical engineer (Section 4.2.3.2), he indicated that he agreed with this interpretation. He noted that the context of his work at that time did not involve performing computations on data, and that he was primarily working on the development and evaluation of tests.

The last element that was not present across all four of the engineer cases was *Transparency.* This element was represented in the work of the chemical, civil, and biological engineers, but was not represented in the work of the electrical engineer. There were no instances observed of the electrical engineer explicitly describing how he was being clear, upfront, or fair about where information came from or the processes that he was enacting. However, this finding does not indicate that he never enacted *Transparency* while working. During the member-checking session with this engineer (Section 4.2.3.2), he indicated that the researcher may have been observing him on a day or time that he was not explicitly enacting this behavior.

CHAPTER 5

DISCUSSION

This study explores how habits of mind are represented in the work of four practicing engineers employed across separate workplace contexts within one western region of the United States. Using primary data sources (i.e., engineers' company websites, the researcher's reflective memos, and notes from member-checking sessions) and secondary data sources (i.e., field notes from observations, interview transcripts, think-aloud transcripts, and engineer participant resumes), the researcher's data analysis revealed five broad habits of mind that were common across all four engineer cases. This chapter discusses how the findings of this study compare to existing habits of mind frameworks that are either axiological or epistemological in nature.

Five habits of mind were identified from the data analysis of the four practicing engineer cases. These habits of mind included being *Problem-focused, Interpersonal, Self-reflective, Mindful of the bigger picture*, and *Technically adept.* Each of these habits are comprised of several elements either generated by the researcher during the analysis or previously identified in the literature. *Findings from this study provide evidence to confirm existing conceptualizations of habits of mind in engineering while offering a new approach for conceptualizing engineering habits of mind as inherently value (axiological) and knowledge (epistemological) -based.*

One conceptual framework that informed this dissertation study was the habits of mind framework proposed by the American Association for the Advancement of Science (AAAS) in the Project 2061: Science for All Americans report (Rutherford & Ahlgren, 1990). This framework conceptualized habits of mind in terms of values, attitudes, and skills. Values were further defined by three individual elements: curiosity, openness to new ideas, and informed skepticism. Skills were also further defined in terms of computation, manipulation and observation, communication, and critical response. Attitudes were conceptualized as how one perceived their own knowledge, what informed those perceptions, and taking interest in one's learning. The Project 2061 framework is axiological in nature because it accounts for how values and attitudes shape one's thinking during problem solving or facing uncertainty. This framework suggests that these axiological components are essential to how habits of mind should be conceptualized and should be incorporated into science and engineering education to support students' development into a scientifically literate society.

The second conceptual framework that informed this study was the Engineering Habits of Mind (EHoM) framework proposed by engineering education researchers Lucas and Hanson (2016). This framework described six individual habits of mind including "systems thinking," "problem finding," "visualizing," "improving," "creative problem-solving," and "adapting." This framework is epistemological in nature because it conceptualized habits of mind in terms of the ways engineers think about and produce engineering knowledge.

The five habits of mind that were identified in this dissertation study incorporate elements from both conceptual frameworks. *The results of this study reveal that the habits of mind represented in the work of four practicing engineers comprise inter-related axiological and epistemological elements; these philosophically diverse elements,* *which currently comprise separate models of engineering habits of mind in the science and engineering education literature, can be represented by a single conceptual model*.

Findings from this study highlight the ways in which common habits of mind are exhibited in different ways based on the context of the engineers' work environment and role. Previous research has not investigated how habits of mind in engineering may be represented across different engineering contexts, including in different engineering disciplines, companies, or specific job roles. The results of this study add to the literature by combining and expanding upon current conceptualizations of habits of mind in engineering.

5.1 Habits of Mind Can Be Grouped Broadly

The first research question guiding this dissertation study investigated how habits of mind are represented in the work of four practicing engineers. One important finding from this study is that engineering habits of mind can be conceptualized as broad, aspirational behaviors that engineers employ. These broad habits of mind are then comprised of individual, more specific behaviors that are represented in engineers' work in unique ways depending on the context in which the engineer worked. The five broad habits of mind that were identified from the analysis of the data included being *Problem-focused, Interpersonal, Self-reflective, Mindful of the bigger picture,* and *Technically adept.* Each of these habits of mind grouped specific codes generated from the data by the researcher, from the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990), and from Lucas and Hanson's (2016) Engineering Habits of Mind (EHoM) framework. These individual codes represent how the engineers enacted the broad habits of mind differently in different contexts. Figure 2-1 and Figure 2-2 presented these habits of mind and in the case of the Project 2061 framework (Rutherford & Ahlgren, 1990), the corresponding elements within the habits. The habits within the EHoM framework (Lucas & Hanson, 2016) were presented in an orange color with a (x) symbol. The elements of the Project 2061 framework (Rutherford & Ahlgren, 1990) were presented in a light blue color with a (&) symbol. These colors and shapes can be used to visualize how these elements are represented in the five habits of mind that were identified in this dissertation study.

Figure 5-1 presents an overview of a conceptual model of the five engineering habits of mind that were identified in this dissertation study. The corresponding elements (indicated through color and symbols) from the researcher's analysis and both conceptual frameworks are presented within their respective habit of mind. These colors and shapes are used in Figure 5-1 to show how elements of the two conceptual frameworks are represented in the five habits of mind identified in the present study. The color pink with a (*) symbol is also used to show elements that were generated by the researcher during the analysis.

Figure 5-1

The Five Habits of Mind That Were Identified in This Study and Their Corresponding Elements.

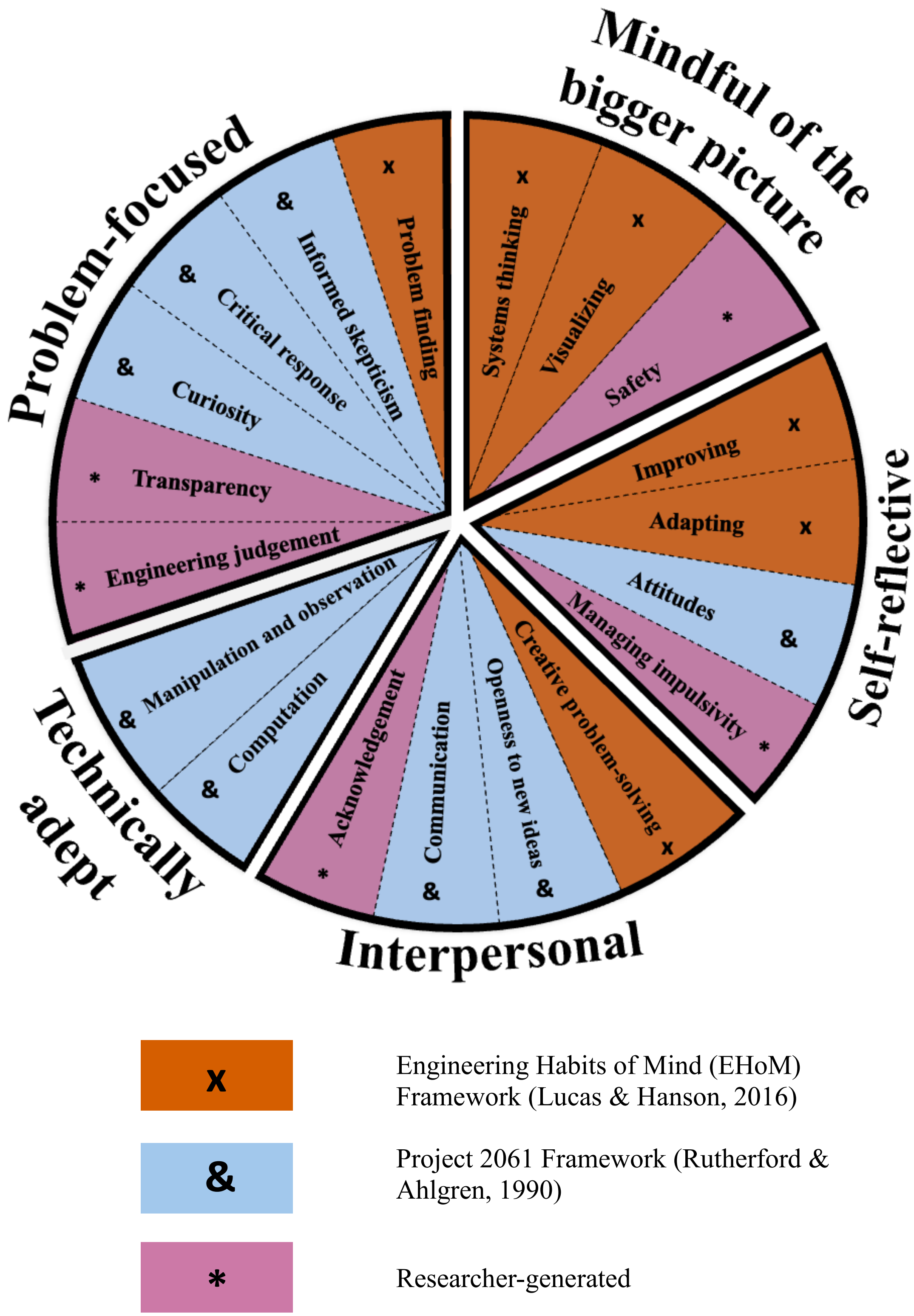


Figure 5-1 demonstrates how the Project 2061 framework (Rutherford & Ahlgren, 1990), the EHoM framework (Lucas & Hanson, 2016), and the elements that were generated by the researcher during the analysis are represented in the five identified habits of mind. These groupings reveal how individual habits of mind elements, both axiological and epistemological, are important to the work of practicing engineers. There is evidence that the four practicing engineers employed elements captured in both the Project 2061 framework (Rutherford & Ahlgren, 1990) and the EHoM framework (Lucas & Hanson, 2016). Each of these habits of mind was represented at least once across all four of the engineer cases. However, not all of these frameworks' elements were represented in each individual engineer case. The ways in which the individual elements were manifested in the work of the practicing engineers was dependent on the context of each engineer case. This finding affirms the assertion that habits of mind can be represented across case contexts, but the specific ways in which they were manifested in the work of the four practicing engineers was dependent on the case context.

5.2 New Insights from Practicing Engineers

This study conceptualizes engineering habits of mind as inherently axiological and epistemological. It also provides insights into new habits of mind and individual elements that were not previously identified in the engineering education literature. These newly identified habits of mind provide further insight into answering the first research question posed for this study. The analysis of the data revealed five new elements that are embedded within the five engineering habits of mind and demonstrate the ways in which the engineers exhibited habits of mind while working. These new components included

Engineering judgement, Transparency, Acknowledgement, Managing impulsivity, and *Safety.*

These new findings suggest the importance that studying habits of mind of engineering practitioners has for the field of engineering education. Previous literature exploring habits of mind in engineering has focused on studying how undergraduate engineering students make use of habits of mind (e.g., K. Johnson et al., 2019; Pitterson et al., 2018; Yellamraju et al., 2019). The findings of these studies confirmed that undergraduate engineering students employed habits of mind as conceptualized by the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990). These studies investigated how habits of mind, defined in terms of values, attitudes, and skills, were represented in undergraduate engineering students' work. These studies did not explore any new habits of mind that may have been present in the data, nor did they code for more specific habits of mind beyond values, attitudes, and skills. Furthermore, these studies did not integrate other conceptualizations of habits of mind, such as the EHoM framework proposed by Lucas and Hanson (2016).

5.2.1 Contextualizing the Project 2061 Habits of Mind Framework for Engineering Practice

5.2.1.1 Values

In their prior investigation of how undergraduate electrical engineering students used habits of mind in the classroom, Pitterson et al. (2018) defined "values" as: "Making decisions about what concepts are relevant to their understanding and how to gauge conceptual scientific knowledge" (p. 5). The authors described how the undergraduate engineering students enacted "values" when they indicated that it was important for them to see practical applications of their academic work. One student respondent in the study described that being able to physically interact with engineering tools, such as an oscilloscope, gave them a better understanding of the concept as opposed to working with equations and theoretical concepts (Pitterson et al., 2018).

In contrast, during the analysis portion of this dissertation research study, the “values” component of this habits of mind framework was removed and the underlying components related to “values” were grouped into categories that were conceptually similar (i.e., into the five habits of mind themes discussed in Section 4.1). The elements that were originally identified as “values” in the Project 2061 habits of mind framework, including *Curiosity, Openness to new ideas,* and *Informed skepticism* (Rutherford & Ahlgren, 1990), were removed from the “values” category during the axial coding stage of the second coding cycle as outlined in Table 4-3. The habits of mind that were originally conceptualized as “values” were grouped with other habits that shared similar core ideas and were able to be expanded into a broader habit of mind that applied to engineers working in different contexts and environments.

5.2.1.2 Attitudes

Additionally, the definition for “attitudes” differed between this dissertation research and Pitterson et al.’s (2018) study. Pitterson et al. (2018) defined “attitudes” as: “How past knowledge and experiences shape/form their current understanding about science/engineering learning” (p. 5). They found that undergraduate engineering students exhibited the “attitudes” habit of mind when describing what influenced them to pursue engineering in university. The authors also found that “attitudes” were represented through the undergraduate students viewing their ability to utilize prior knowledge when confronted with an unfamiliar engineering concept as a positive academic achievement.

In contrast, the definition for "attitudes" for this dissertation study was: "having a positive disposition toward learning science, mathematics, and engineering" (Rutherford & Ahlgren, 1990). This definition more closely aligned with how "attitudes" were expressed in the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990). The results of the present study suggest that the practicing engineers exhibited positive attitudes when describing their motivations for pursuing engineering. In contrast, the undergraduate students in Pitterson et al.'s (2018) study represented the habit of "attitudes" when discussing factors that influenced them to pursue engineering in university. The undergraduate students in Pitterson et al.'s (2018) study commonly described how they were influenced by family members to pursue engineering and that led to their interest in the discipline. As described in Section 4.1.3.1, the practicing engineers exhibited "attitudes" when describing what was rewarding about their careers and what they enjoyed about their jobs. They indicated that feeling challenged and having the opportunity to learn new things each day were positive attributes of their careers that kept them in the profession. These results highlight the differences between how "attitudes" are conceptualized for undergraduate engineering students and how they are represented in the work of their professional counterparts.

5.2.1.3 Skills

Last, Pitterson et al.'s (2018) study explored how "skills" were represented in the work of the undergraduate engineering students. The authors defined skills in terms of "computation" and "manipulation and observation" as described in the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990). This included performing computations, using equations, and applying theoretical knowledge to laboratory work. They found that students exhibited “skills” when they used equations to develop an understanding of the relationship between variables given in each problem. Their results also revealed that students used estimation strategies as a first approach when solving a problem (Pitterson et al., 2018).

These findings are like those obtained from the results of the present study. The analysis of the engineer cases revealed that all four engineers employed the use of technical skills in terms of “manipulation and observation” and “computation.” These two elements comprised the *Technically adept* habit of mind. As described in Section 4.1.5, this habit of mind was characterized by the engineers using physical manipulatives, such as testing setups, or computation tools, such as computer programs or calculators, to solve problems. These results indicate that an important habit of mind for engineering practice is to be able to utilize technical skills to accomplish goals. In addition to confirming that the “skills” habit of mind is represented in the work of practicing engineers in addition to undergraduate students, this study revealed deeper insights into how this habit was represented in different contexts. As described in Section 4.3.5, each engineer case employed the *Technically adept* habit of mind theme differently depending on their discipline, specific job function, and the project they were working on for their company. These results provide further insights into how the *Technically adept* habit of mind is represented in engineering work and that it is dependent on the context in which the engineer worked.

5.3 Importance of Case Context

The second research question of this study aimed to understand how habits of mind compared and contrasted across the four individual engineer cases. Analysis of both primary and secondary data sources was conducted to explore this research question, including reflective memos written by the researcher; notes taken during member-checking sessions with the engineer participants; information from company websites; field notes from observations; transcripts from interview and think-aloud sessions; and information from each engineer's resume.

Insights from the first research question suggested that current conceptualizations of how habits of mind have been studied in engineering are applicable to practicing engineers working in industry. Additionally, the findings revealed that there were specific ways in which the engineers exhibited habits of mind that were identified by the researcher that were not accounted for in the current habits of mind literature. Lucas and Hanson's (2016) work developing the Engineering Habits of Mind (EHoM) framework confirmed through interviews with engineers that their six identified habits of mind reflected what they perceived to be true about habits necessary for success in engineering practice. However, the habits of mind represented in the EHoM framework were not generated from data directly obtained from the work of practicing engineers.

Additionally, there are no current studies in engineering education that have explored how these habits of mind are used at different engineering workplaces. The results of this dissertation study revealed that how the engineers employed habits of mind depended on the four engineer case contexts. For this study, the case context acknowledges the four different engineering disciplines; the engineers' specific job roles;

the engineers' workplace contexts, including size and scope; and the engineers' gender identity (details provided in Table 3-3).

One aspect of the case contexts that informed how the engineers used habits of mind was the influence of each engineer's job role. For example, the chemical engineer case primarily analyzed data and managed the relationships between people and processes for a company that produced products for human consumption. Her work did not necessitate the use of the *Manipulation and observation* element within the broader habit of being *Technically adept.* Her role did not require her to make physical observations of the production lines or machinery on the production floor. However, she did employ the *Computation* element that was included in the *Technically adept* habit of mind. She performed analysis on data that described the production output and efficiency of the plant. This finding contrasts how the electrical engineer used the *Technically adept* habit of mind. His job function required him to use the *Manipulation and observation* element as he built and tested physical electrical setups. However, because much of his work was centered on designing, building, and testing these physical components, he did not demonstrate any instances of *Computation* to accomplish his work. The electrical engineer's work role and job function required the use of the *Technically adept* habit of mind, but the way in which this habit was represented in his work differed from how being *Technically adept* was represented in the chemical engineer's work.

This finding can also apply to the work of the civil and biological engineers. Both of these engineer cases used both the *Manipulation and observation* and *Computation* elements of the *Technically adept* habit of mind. However, the frequency with which they used these habits (as shown in Table 4-10 and Table 4-12) and the way they enacted these habits differed depending on the engineers' contexts. The biological engineer used *Manipulation and observation* when she went to site locations to disassemble products and troubleshoot points of concern. The civil engineer used *Manipulation and observation* when he evaluated site conditions from photographs or used scaling tools to perform computations related to improving a map plan. Similarly, the biological engineer used *Computation* when she designed computation programs that generated predicted output from a design. The civil engineer used *Computation* when he validated calculations in submittals for construction or on map plans.

These examples suggest that individual elements (e.g., *Manipulation and observation* and *Computation*) that were identified by previous engineering education researchers are reflected in the work of practicing engineers. However, these examples highlight that the ways in which these habits are enacted are dependent on the context in which the engineers worked, including each engineer's role within their company. The results of this study suggest that individual elements can be conceptualized into a broader habit of mind that are both axiological and epistemological in nature and can be transferred across different contexts.

Additionally, the findings generated from each of the four engineer cases in this study are not fully representative of how other engineers in these four disciplines may use habits of mind at the workplace. For example, the electrical engineer in this dissertation study did not perform any mathematical computations during his work. As described in Section 3.9.2.1, his role was in the design and testing of hardware systems. He would analyze and interpret data and results from tests, but he would not perform calculations on or manipulate this data in any way. This type of work focus is not applicable to all types of electrical engineers working in this discipline. Other electrical engineers may use *Computation* at the workplace to accomplish their job functions. Therefore, the results of this study do not provide a complete picture of how all engineers in the four chosen disciplines use habits of mind at the workplace. However, these findings reveal the importance that the engineers' job roles have on how they employ habits of mind while working.

A second aspect of the engineer case contexts that may have informed the findings of this study is each engineer's level of experience within their company. As described in Section 3.9.2, three of the engineers that participated in this study had worked in industry for at least 10 years (i.e., the chemical, electrical, and biological engineers). One of the engineers (i.e., the civil engineer) had worked formally as an engineer for three years and as an engineering technician for three years while completing his bachelor's degree in civil engineering. These levels of experience within their disciplines and within each of their companies may have affected how the engineers used habits of mind at the workplace. Different levels of experience and, accordingly, different roles within an engineering company may require engineers to use habits of mind in different ways to meet the needs of different job functions. Novice engineers that are "newcomers" (Lave, 1991, p. 72) to the engineering community of practice may use different habits of mind when solving problems or working with others. Additionally, they may employ habits of mind in different ways compared to more advanced engineers (i.e., "oldtimers" (Lave, 1991, p. 72)).

In Lucas and Hanson's (2016) interviews with engineers regarding their perceptions of the Engineering Habits of Mind (EHoM) framework, the engineers suggested that different habits of mind may be more “sophisticated” (p. 6) than others. Certain habits of mind may have been more likely to be enacted by engineers that had more experience solving the types of engineering problems that each engineer commonly encountered at the workplace. This insight suggests that each engineer’s level of experience working in their discipline and/or at their company may have impacted the habits of mind they employed and the specific ways in which they enacted these habits.

This study expands upon current habits of mind frameworks that have been used in engineering education (e.g., Lucas & Hanson, 2016; Rutherford & Ahlgren, 1990) by combining individual habits from these frameworks with habits that were generated directly from the data with practicing engineers. This study further expands the understandings of habits of mind in engineering by grouping these individual habits into broader themes that transcend across engineering disciplines, workplace contexts, and engineer job functions.

5.4 Growing This Habits of Mind Framework

The five habits of mind that were identified in this study and their corresponding elements may not fully represent the multitude of ways in which practicing engineers exhibit habits of mind at the workplace. There may be additional elements of the five habits of mind that were not identified during the analysis of the four engineer cases. For example, one way that an engineer may employ the *Technically adept* habit is through using computer-aided design (CAD) or finite element analysis (FEA) software. Engineers working in other engineering disciplines or workplace contexts may also exhibit the habit of *Technically adept* through writing computer programs or working with software code.

Similarly, the *Mindful of the bigger picture* habit of mind may be represented in other ways that were not captured by the four engineer participants in this study, such as considerations of macro- and micro-ethics when solving problems or generating solutions. These types of ethical considerations could include considerations of sustainability; short and long-term environmental impacts; and how professional and personal ethics affect decision-making at the engineering workplace.

These types of considerations suggest areas in which the conceptualization of habits of mind proposed in this dissertation study could be expanded. This framework serves as a starting point from which future work can be conducted to uncover ways in which practicing engineers use habits of mind in contexts that differ from those in this study. These contributions can improve upon the findings of this study and make the framework more representative of engineers working in more diverse contexts across disciplines, workplaces, locations, and cultures. New findings can readily fit into the framework of five habits of mind that was presented in this study and can account for other ways that practicing engineers exhibit habits of mind in different contexts.

CHAPTER 6

CONCLUSIONS

Habits of mind have been suggested as one approach to equipping undergraduate students with the essential skills and characteristics that are necessary for success in professional practice (Costa & Kallick, 2008; Katehi et al., 2009; Rutherford & Ahlgren, 1990). This study investigated how habits of mind were represented in the work of practicing engineers from four disciplines of engineering, each situated within their own diverse context. This study contributes to the body of research on habits of mind in engineering by incorporating perspectives from the authentic work of engineers in practice into current conceptualizations of habits of mind that were derived from an academic perspective. Findings confirmed that current conceptualizations of habits of mind in engineering are applicable to practicing engineers working in industry. The results of this study also revealed insights into new behaviors and ways of thinking that have not been previously identified in current habits of mind frameworks for use in engineering education. This study proposed a new way of conceptualizing habits of mind such that individual axiological and epistemological elements coexist together and are interrelated more broadly. This study also suggested new ways of describing how practicing engineers exhibit the five identified habits of mind in authentic engineering work environments and conceptualized them into a single model.

6.1 Implications for Teaching Practice

One broad habit of mind that was identified from the analysis of the data was *Problem-focused*. This habit of mind encapsulates elements that relate to the identification and contextualization of problems, while also being cognizant of the credibility of information and how to make decisions about potential solutions. This habit of mind is central to the work of the four engineer cases and demonstrates the importance that establishing contexts, asking questions, and judging solutions has as engineers solve problems at the workplace. Undergraduate engineering programs should afford students the opportunity to hone these abilities so they are able to develop this habit of mind. Students can work on defining and contextualizing the problems they solve rather than being given an explicit problem statement (*Problem finding*). This could prompt them to ask questions to clarify the problem or explore potential solutions (*Curiosity*). This process could also involve students making judgements about the credibility of their chosen solution (*Critical response*) or the solutions proposed by fellow classmates.

Interpersonal was also identified as a habit of mind from the analysis. This habit suggests the importance of being able to interact with, listen to, and be receptive to the ideas of others. Being *Interpersonal* was central to the work of all four engineers as they generated solution ideas with others, made justifications about design decisions to colleagues or stakeholders, and recognized the contributions that others brought to a team. Analysis of all of the engineer participants' data revealed the importance that working with others and being able to convey and retain information had on their work as engineers. Therefore, it is critical that undergraduate engineering students are afforded opportunities to work and interact with others to enhance their ability to be *Interpersonal*.

Students can learn how to enhance their own communication skills by giving presentations to the class or by contributing their ideas to a group problem (*Communication*). Working in teams would allow students to learn how to approach problems as a group rather than individually (*Creative problem-solving*), allowing them to also learn how to be receptive to perspectives that may differ from their own (*Openness to new ideas*).

Self-reflective was another habit of mind identified from the data. This habit of mind was reflected in the work of all four practicing engineers in how they were contemplative about their decisions and actions, how they maintained personal composure remained thoughtful and deliberative about solutions, and the ways in which they expressed a positive attitude toward their careers and the field of engineering. All four of the engineer cases exhibited evidence of being *Self-reflective* when they were solving problems and working with others. Undergraduate engineering students should be provided with opportunities to reflect on the decisions they have made and consider their relevance to the problem they are attempting to solve. Students should also be encouraged to practice thinking mindfully about solution strategies and their interactions with others as they solve problems. These types of behaviors would encourage students to develop the *Self-reflective* habit of mind and the ability to remain thoughtful, deliberative, and reflective throughout the problem solving process.

The fourth habit of mind that was identified was being *Mindful of the bigger picture.* This habit of mind was characterized by how the engineers viewed problems and solutions holistically, understanding that situations are comprised of many complex interrelated components that have impacts on stakeholders, fellow employees, and the environment. Undergraduate engineering students can be encouraged to develop a *Systems thinking* approach to problem-solving in the classroom that enables them to think broadly about solution ideas. Students can investigate the *Safety* implications for a product they are designing, such as the potential safety hazards associated with using the product and how they will be mitigated. Students can also be taught the benefit of *Visualizing* final products of a solution design and their feasibility for practical applications. Mechanical engineering students can consider whether the materials they have chosen for construction of a design have the allowable properties for a biological reaction to take place successfully. Similarly, electrical engineering students can decide how to build a piece of circuitry that must fit into a structural housing that was developed by mechanical engineers.

The final habit of mind that was identified from the analysis of this study was the ability to be *Technically adept.* This habit of mind was represented in the engineers' work as they used physical manipulatives, testing setups, and computation tools to solve problems. Undergraduate engineering students should be affirmed that the ability to apply theoretical knowledge to practical situations is important to engineering practice. Laboratory experiences are one way for students to gain practice employing the *Manipulation and observation* habit of mind. Students can set up and run experiments or tests to make observations and collect data. They can use visual evidence to determine how to approach a problem or generate a solution. Additionally, students' *Computation* habit of mind can be strengthened through writing calculation programs, understanding equations and dependencies between variables, and manipulating data. During the member checking session with the chemical engineer, she affirmed the importance of being able to manipulate data and perform statistics to solve problems at her job (as discussed in Section 4.2.1.2). Fostering students' abilities to be *Technically adept* will allow students to develop the mathematical reasoning skills that are required for solving complex engineering problems.

6.2 Recommendations for Future Work

Research exploring habits of mind in engineering should continue to be promoted. Additional research with practicing engineers is needed to critique and contribute to the conceptualization of five habits of mind presented in this dissertation study. Future research could explore how habits of mind are represented in the work of engineers in other engineering disciplines, such as mechanical, aerospace, environmental, or computer engineering. To ensure that diverse contexts are represented, engineers working within different levels at their companies should continue to be included. Additionally, future research should explore the work of engineers employed at variety of types of engineering companies (e.g., not-for-profit institutions, companies of different sizes, and both international and domestic-focused companies). Insights from different engineering disciplines and contexts can strengthen understandings about how habits of mind are represented in the work of practicing engineers.

Additional research with more diverse participants is necessary to provide perspectives from engineers from different backgrounds. Future research should investigate how practicing engineers in countries other than the United States perform engineering work and interact socially with others at the workplace. The findings from the four engineers included in this dissertation study are not representative of all engineers working across all different types of contexts. Accordingly, there may be core engineering habits of mind used by engineers working in different contexts that were not captured in this study. Research with engineers from diverse backgrounds and cultures can supplement the findings of this dissertation study and provide valuable insights into how habits of mind are represented in their work. The framework for habits of mind presented in this dissertation study can be expanded to include these types of additional perspectives. Future insights can then contribute to a more holistic understanding of how habits of mind are represented in engineering practice that accounts for diverse perspectives and contexts.

Additionally, future research should explore whether and/or how habits of mind and their corresponding elements are represented in the context of engineers' gender identity. For example, the two engineers that identified as female for this study (i.e., the biological and the chemical engineer) both exhibited the *Managing impulsivity* element of being *Self-reflective*, while neither of the two male engineers (i.e., the civil and the electrical engineer) exhibited this element. This finding may have been due to both the biological and chemical engineer identifying as female. This finding could also be due to the context of these engineers' job role or work environment. Future work exploring how habits of mind are represented across different genders can provide insights into this type of finding and how or whether engineers of different genders use habits of mind differently at the workplace.

Additional work should be conducted to explore how undergraduate engineering students use habits of mind and how their usage compares to that of practicing engineers. Research in this area could explore how undergraduate engineering students employ different habits of mind elements when solving academic problems or working with others. Other research could explore whether there are additional broad habits of mind that students use that may differ from the habits that are used by engineers working in industry. Findings could be compared and contrasted to identify salient habits of mind that are used by engineering students and how these relate to those used by practicing engineers.

Last, future research is also needed to further explore the use of current habits of mind conceptual frameworks and if the use of these frameworks is confirmed in other research settings and with more diverse engineers. The results of this study provided evidence that the Project 2061 habits of mind framework (Rutherford & Ahlgren, 1990) and Lucas and Hanson’s (2016) Engineering Habits of Mind (EHoM) framework had elements that were represented in the work of the engineers in the present study. Additional research could explore how the habits of mind in these frameworks are represented in the work of engineers working in contexts that are different from those in this study. This type of work could also reveal other new habits of mind that may be represented in by engineers working in these contexts. Findings from these types of future research studies will contribute to current understandings of habits of mind in engineering and can lead to positive impacts for improving undergraduate engineering education. Engineering students that are afforded opportunities to develop relevant engineering habits of mind can be better prepared to approach problems with an engineering mindset and encourage their pursuit of engineering careers in the workforce.

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APPENDICES

APPENDIX A

SAMPLE INTERVIEW AND THINK-ALOUD PROTOCOL

Questions Related to Writing or Text Production

It seems like, based on your log and our observations, the type of text that you produce most often is [XX text]. Is our perception correct?

- What do you see as the role of [XX text] in engineering?
- What are your criteria for determining the quality of [XX] text?

I noticed from [your log, observations] that you produced [XX text]. Can you please tell me more about the process of creating it?

- Who or what did you consult in the process of creating it?
- What types of revisions did you make as you were creating it?
- Why did you make those revisions?
- How did you know when the text was "done" or ready to be shared?
- What do you see as the role of this type of text in your work?

Think-Aloud Prompt: Thank you for bringing [this text that you produced] to the interview. Would you mind sharing your thought processes as you created this text?

Questions Related to Reading, Interpreting Texts, or Locating Texts

I noticed from your log that you conducted an Internet search on Google. Would you mind retracing your steps for me?

- Which source or sources provided the most useful information?
- What criteria do you use for determining usefulness?
- What criteria do you use for determining reliability or accuracy of sources?
- What role do internet searches play in your work?
- Did you compare the internet sources against any other sources? If so, what were they?

It seems like, based on your log and our observations, the type of text that you read most often is [XX text]. Is our perception correct?

- What do you see as the role of [XX text] in engineering?
- What are your criteria for determining the quality of [XX] text?

I noticed from [your log, observations] that you interpreted [XX text]. Can you please tell me more about why you read this text and how you used it?

- What information did you hope to get out of this text?
- Did you compare and contrast information from this text with other texts? If so, which ones?
- Did this text [or the set of texts] give you enough information to make a decision? If so, how did you know that you had enough information? If not, how did you know that you did not have enough information, and what were your plans to collect more information?
- What criteria did you use to evaluate the quality of information in this text?
- What do you see as the role of this type of text in your work?

Do some texts carry more weight for you in terms of their importance to your work? If so, which ones? Why are these texts more important?

Think-Aloud Prompt: Thank you for bringing [this text that you read] to the interview. Would you mind sharing your thought processes as you created this text?

APPENDIX B

MEMBER CHECKING QUESTIONS

I first want to go over the definition of Habits of Mind with you again so we can be on the same page with the ideas that I'll be sharing today. I've defined habits of mind as "a combination of intelligent, social behaviors that engineers should aspire to have when solving problems and facing uncertainty."

During my analysis of your data, I coded for several habits of mind and have shown their names and the counts associated with them below.

The top 3 habits of mind that I found from the analysis of your data included:

a. [1st top habit of mind]
b. [2nd top habit of mind]
c. [3rd top habit of mind]

My interpretations from these top 3 habits of mind suggest that [description of what these habits of mind mean] are essential to the work that you perform as an engineer.

a. Does this interpretation resonate with you?
b. Do you have any suggestions for improving my interpretation of your work?

1. Throughout the analysis of your data, I've determined that there are 5 major categories of habits of mind that were represented in your data and I would like your perspectives on the labels/wording that I have used for them and if they resonate with you.
2. I have been analyzing the data that I have collected with you and have determined that one prominent habit of mind is that of being ***Problem-focused***.
    a. I have described this habit in terms of *contextualizing problems, remaining skeptical of new ideas, remaining critical of new information and its source,* and *using engineering judgement and intuition.*
    b. For example [example from the data].
        i. Does my interpretation of ***Problem-focused*** resonate with you?
        ii. Do you have any suggestions for improving or describing this interpretation?
3. Another prominent habit of mind that I have found is being ***Interpersonal***.
    a. I have described this habit in terms of *solving problems with others, communication skills, acknowledging the perspectives and contributions of others,* and *remaining open to new ideas that may be different from your own.*
    b. For example, [example from the data].
        i. Does my interpretation of ***Interpersonal*** resonate with you?
        ii. Do you have any suggestions for improving or describing this interpretation?
4. Another prominent habit of mind that I have found is being ***Self-reflective***.

a. I have described this habit in terms of *trying to make things better by testing, analyzing or experimenting, remaining reflective and open to changing, being thoughtful and deliberative before acting,* and *maintaining a positive attitude toward learning or engineering.*
b. For example, [example from the data].
    i. Does my interpretation of ***Self-reflective*** resonate with you?
    ii. Do you have any suggestions for improving or describing this interpretation?

5. Another prominent habit of mind that I have found is being ***Mindful of the bigger picture***.
    a. I have described this habit in terms of *systems thinking, visualizing, being open and transparent,* and *adhering to safety.*
    b. For example, [example from the data].
        i. Does my interpretation of ***Mindful of the bigger picture*** resonate with you?
        ii. Do you have any suggestions for improving or describing this interpretation?
6. The final habit of mind that I have found is the idea of being ***Technically adept***.
    a. I have described this habit in terms of *manipulation and observation of physical systems* and *computation abilities.*
    b. For example, [example from the data].
        i. Does my interpretation of being ***Technically adept*** resonate with you?
        ii. Do you have any suggestions for improving or describing this interpretation?

APPENDIX C

LETTER OF INFORMED CONSENT TO ENGINEERS SELECTED FOR PARTICIPATION

Page 1 of 2
Protocol #11505
IRB Exemption Date: 11/11/2020
Consent Document Expires: 11/10/2025

v.9
Informed Consent

Investigating the Habits of Mind of Practicing Engineers

You are invited to participate in a research study conducted by Dr. Angela Minichiello, an Assistant Professor in the Department of Engineering Education at Utah State University and Theresa Green, a Ph.D. Candidate and Graduate Research Assistant in the Department of Engineering Education at Utah State University.

The purpose of this research is to develop an understanding of how habits of mind (i.e., values, attitudes, and skills) are represented in the work of practicing engineers. Specifically, we are interested in learning about how you have used habits of mind (i.e., values, attitudes, and skills) while solving problems at your workplace. You are being asked to participate in this research because you participated in a National Science Foundation (NSF) funded study with our research team previously.

Your participation in this study is voluntary and you may withdraw your participation at any time for any reason.

If you take part in this study, you will be asked to:

- Give permission to the research team to use the data we collected with you as part of the previous study in which you participated with us, Learning from Engineers to Develop a Model of Disciplinary Literacy in Engineering (IRB Protocol #8136), for analysis in this new study investigating habits of mind of practicing engineers. Data to be re-analyzed consists of field notes from the on-site observations and transcripts from the interviews and think-alouds that we conducted.
- Participate in one (1) member-checking session during the spring of 2021. This member-checking session will be conducted virtually at a time and date that is convenient for you. A member-checking session allows for you to provide your feedback on the analysis and interpretations that have been drawn by the research team. This session will last between 30 to 45 minutes.

The possible risks of participating in this study are no more likely or serious than those you encounter in everyday activities. The foreseeable risks or discomforts include a slight risk of loss of confidentiality. There is also a risk that you might feel discomfort when discussing interpretations about data we collected with you.

We will make every effort to ensure that the information you provide remains confidential. We will not reveal your identity in any publications, presentations, or reports resulting from this research study. However, it may be possible for someone to recognize the specifics you share with us. If there is identifying information in the data we have collected with you, it will be deidentified before analysis.

We will collect your information through interviews and field notes that were collected from the NSF study that you previously participated in with our research team. Online activities always carry a risk of a data breach, but we will use systems and processes that minimize breach opportunities. Data will be securely stored in a restricted-access folder on Box.com, an encrypted, cloud-based storage system and on a password-protected computer owned by Utah State University that only the student researcher is able to access.

You can decline to participate in any part of this study for any reason and can end your participation at any time.

If you have any questions about this study, you can contact the Principal Investigator at angie.minichiello@usu.edu or the student researcher at theresa.green@usu.edu. Thank you again for your time and consideration. If you have any concerns about this study, please contact Utah State University's Human Research Protection Office at (435) 797-0567 or irb@usu.edu.

v.9

By signing below, you agree to participate in this study. You indicate that you understand the risks and benefits of participation, and that you know what you will be asked to do. You also agree that you have asked any questions you might have, and are clear on how to stop your participation in the study if you choose to do so. Please be sure to retain a copy of this form for your records.

______________________	______________________	__________
Participant's Signature	Participant's Name, Printed	Date

APPENDIX D

EMAIL TO POTENTIAL ENGINEER PARTICIPANTS

Dear [Engineer name],

Hello! I hope you are doing well. This is Theresa Green from Utah State University. I am reaching out to you because you participated in an NSF funded study with our research team from [month year to month year]. During that time, I observed you at your workplace and interviewed you about your workplace communication practices.

I am now in the process of writing my Ph.D. dissertation with plans to graduate in late Spring 2021. As part of my dissertation research study, I hope to re-analyze the data that you shared with us to answer new research questions (separate from those of the NSF funded study) regarding habits of mind in engineering. Habits of mind are the "intelligent behaviors" that people exhibit when solving problems, evaluating arguments, and dealing with uncertainty. Some examples of habits of mind include "curiosity," "openness to new ideas," "informed skepticism," and "critical-response skills."

As part of this process, I am asking for your permission to re-analyze the data that I previously collected with you (including field notes from my on-site observations and transcripts from our interviews and think-alouds) to investigate how habits of mind are represented in your work as a practicing engineer.

Second, as part of my data analysis procedures, I'd like to conduct participant member checking with you to validate my interpretations of your data. Participant member checking is a technique used in qualitative research to ensure quality and avoid my own personal bias in the analysis process. The participant member checking process would involve us having a short (30-45 minutes), one-time discussion (via Zoom, Teams, etc.) in which you would have the opportunity to provide your opinions and feedback on my initial interpretations that I have made from the observation and interview data that I collected with you. This would likely occur sometime in the spring of 2021. I will work with you flexibly to determine a time for this meeting that works well for you.

I have attached a Letter of Informed Consent for this study. This Letter has been approved under IRB Protocol #11505 at Utah State University. After reading over the information in the Letter, there will be an area for you to sign or upload a digital signature indicating that you consent to the procedures that are outlined, including permission to re-analyze the data I collected with you as part of the previous study and willingness to participate in a one-time (30-45 minutes) virtual member-check.

Please read over the information in the Letter and indicate your consent by signing or uploading a digital signature to the form. You may contact myself (theresa.green@usu.edu) or the Principal Investigator of this project, Angela Minichiello (angie.minichiello@usu.edu) if you have any questions about the process or the study in general.

I appreciate your time and consideration.

Thank you,
Theresa Green
Graduate Research Assistant
Department of Engineering Education | Utah State University
theresa.green@usu.edu

CURRICULUM VITAE

Theresa Green
648 E 800 N #304 | Logan, UT 84321 | theresa.green@usu.edu

Education

2017 - 2021 Ph.D., Engineering Education, Utah State University

- Dissertation: *Investigating the Habits of Mind of Practicing Engineers*
- Ph.D. Qualifying Exam completed February 2020
- Ph.D. Proposal Defense completed October 2020

2017- 2020 M.S., Mechanical Engineering, Utah State University

2013 - 2016 B.S., Mechanical Engineering, Valparaiso University

Research Experience

July 2017 – Dec 2020 **Graduate Research Assistant**, Department of Engineering Education, College of Engineering, Utah State University

- Employed qualitative research methods to help generate an extensive, in-situ data set collected with practicing engineers.
- Engaged with research team members to analyze and synthesize data.
- Developed and presented conference papers and presentations to national and local audiences.
- Faculty advisor: Angela Minichiello, Ph.D., P.E.

May - Aug 2016 **Research Assistant**, College of Engineering, Valparaiso University

- Performed quantitative data analysis in SPSS.

- Conducted a literature review regarding conceptual understanding in engineering statics for a grant proposal.
- Assisted mentor in writing conference papers.
- Faculty mentor: Ruth Wertz, Ph.D.

Jun - Aug 2015 **Research Assistant**, Department of Mechanical Engineering, Missouri University of Science and Technology

- Assisted mentor with laboratory work and experimental designs to meet research goal of developing ink for printing transient electronic devices.
- Faculty mentor: Xian Huang, Ph.D.

Graduate Teaching Experience

May – Dec 2020 **Graduate Teaching Fellow**, College of Engineering, Utah State University

MAE 1500: Introduction to Engineering

- Assisted teaching an undergraduate introduction to engineering course by lecturing, designing assignments and assessments, and interacting with students.
- Developed and delivered synchronous and asynchronous classroom content through in-person and online methods.
- Teacher aided: Darcie Christensen, M.Eng.

Work Experience

Dec 2020 – April 2021 **National Science Foundation Intern**, Smithsonian Science Education Center (SSEC)

- Evaluated and revised the SSEC's Smithsonian Science for the Classroom (SSftC) Grade 1 and Grade 2 engineering

curriculum modules in accordance with the Next Generation Science Standards (NGSS) by:
    - Assessing and revising lesson plans
    - Testing new activities
    - Preparing supplemental learning content
- Contributed technical engineering knowledge, engineering education research knowledge, and personal perspectives on the content of the SSftC Grade 1 and Grade 2 engineering curriculum modules.
- Supervisor: Sarah Glassman, Ph.D.

Dec 2016 - Jun 2017

Mathematics Instructor, Mathnasium of Orland Park

- Provided personalized mathematics instruction to K-12 students.
- Helped students develop deep understanding of math concepts in ways that made sense to them.

Aug - Dec 2016

Fluid Mechanics Grader, College of Engineering, Valparaiso University

ME 373: Fluid Mechanics

- Graded 3rd-year mechanical engineering students' fluid mechanics homework and provided feedback on their work.
- Faculty mentor: Michael Doria, Ph.D.

Aug 2015 - Dec 2016

Private Tutor

- Assisted local middle and high school students with their schoolwork and prepared them for future classes.

- Encouraged students to excel in mathematics classes and enjoy learning difficult subjects.

Honors and Awards

2020	**Doctoral Student Researcher of the Year**, Department of Engineering Education, Utah State University
2019	**Best Zone II Paper**, 2018 Best American Society for Engineering Education (ASEE) Section Papers
2018	**Best Paper**, 2018 IL/IN Regional American Society for Engineering Education (ASEE) Conference
2016	**Dean's List**, College of Engineering, Valparaiso University
2015	**Dean's List**, College of Engineering, Valparaiso University

Grants and Funding

July 2020	**Non-Academic Research Internships for Graduate Students (INTERN) Supplemental Funding Opportunity**, National Science Foundation, $16,911
February 2019	**PhD Student Travel Grant**, College of Engineering, Utah State University, $300
February 2019	**Graduate Student Travel Award**, School of Graduate Studies, Utah State University, $400
October 2016	**Travel Grant**, Engineering Education Graduate Program Open House, Purdue University, $250
December 2015	**Undergraduate Research Grant**, Creative Work and Research Committee, Valparaiso University, $500 Project Title: *3D Printer Filament Recycler*

September 2015 — **Travel Scholarship**, The Big Ten+ Graduate School Exposition, Purdue University, $500

Publications and Professional Presentations

Journal Publications

1. Wilson-Lopez, A., Minichiello, A., **Green, T.**, Hartman, C., & Washburn, K. (In Preparation). A Comparative Case Study of Engineers' Literacy Practices and Implications for Disciplinary Literacy Pedagogies in Engineering Education. *Reading Research Quarterly*.

Peer Reviewed Conference Papers with Presentations (Presenter underlined)

1. Wilson-Lopez, A., Minichiello, A., **Green, T.**, Hartman, C., and Garlick, J. (2020*). Learning from Engineers to Develop a Model of Disciplinary Literacy in Engineering*. Literacy Research Association (LRA) Annual Conference, Houston, TX.
2. **Green, T.**, Minichiello, A., Wilson-Lopez, A., Hartman, C. & Garlick, J. (2020). *Learning from engineers to develop a model of Disciplinary Literacy Instruction in engineering (Year 3)*. Proceedings of the 2020 Annual ASEE Conference & Exposition, Virtual.
3. Wilson-Lopez, A., Minichiello, A., & **Green, T.** (2019). *An Inquiry Into the Use of Intercoder Reliability Measures in Qualitative Research*. Proceedings of the 2019 ASEE Annual Conference & Exposition, Tampa, FL.
4. **Green, T.**, Wilson-Lopez, A., & Minichiello, A. (2019). *Examining the Literacy Practices of Electrical Engineers: A Comparative Case Study*. Proceedings of the 2019 Annual Meeting of the American Educational Research Association, Toronto, Canada.
5. **Green, T.** & Wertz, R. E. H. (2018). *Research to Practice: Leveraging Concept Inventories in Statics Instruction*. Proceedings of the 2019 Annual ASEE Conference & Exposition, Tampa, FL.

Peer Reviewed Conference Papers with Poster Presentations (Presenter underlined)

1. **Green, T.**, Minichiello, A., & Wilson-Lopez, A. (2019). *Developing a Model of Disciplinary Literacy Instruction for K-12 Engineering Education: Comparing the Literacy Practices of Electrical and Mechanical Engineers (Fundamental)*. Poster presented at the 2019 ASEE Annual Conference & Exposition, Tampa, FL.
2. **Green, T.**, Minichiello, A., & Wilson-Lopez, A. (2018). *Examining the Literacy Practices of Engineers to Develop a Model of Disciplinary Literacy Instruction for K-12 Engineering (Work in Progress)*. Poster presented at the 2018 ASEE Annual Conference & Exposition, Salt Lake City, UT.
3. **Green, T.** & Wertz, R. E. H. (2016). *Validating Instructor-Created Multiple-Choice Statics Exams Using the Concept Assessment Tool for Statics*. Poster presented at the Fall Interdisciplinary Research Symposium, Valparaiso, IN.

White Papers

1. **Green, T.** (August 2021). *Thinking like an Engineer: How All Elementary Students Can Learn to Solve Problems like an Engineer*. Smithsonian Science Education Center (SSEC). EdWeek.org.

Peer Reviewed Curricular Materials

1. Hartman, C., Wilson-Lopez, A., Minichiello, A., & **Green, T**. (submitted). *Using Data to Manage Your Vending Machine*. Teach Engineering: STEM Curriculum for K-12. https://www.teachengineering.org
2. Hartman, C., Wilson-Lopez, A., Minichiello, A., & **Green, T.** (accepted*). Improving Your School's COVID-19 Procedures Using the Engineering Design Process*. Teach Engineering: STEM Curriculum for K-12. https://www.teachengineering.org

Poster Presentations (Presenter underlined)

1. Christensen, L., Foy, W., **Green, T.**, Homer, S., Luebcke, T., & Takacs, N. (2016). *3D Printer Filament Recycler*. Poster presented at the Celebration of Undergraduate Scholarship, Valparaiso, IN.
2. **Green, T.** & Wertz, R. E. H. (2016). *Engineering Outreach in Elementary School: Is Once Enough?* Poster presented at the IL/IN Regional ASEE Conference, Quad Cities, IL.
3. **Green, T.**, Mahajan, B. K., & Huang, X. (2015). *A Low-cost Fabrication Method for Zinc Nanoparticles for Printable Transient Electronic Devices*. Poster presented at the Annual International SFF Symposium, Austin, TX.

Research Datasets

For my graduate research assistantship at Utah State University, I generated an extensive qualitative dataset for an NSF Research in the Formation of Engineers (RFE) project (NSF Award 1664228). This dataset consists of written field notes from on-site observations and transcripts from audio-recorded interviews and think-aloud protocol sessions conducted with eight practicing engineers at eight different engineering companies. Over three and one-half years, I conducted 96 (2-hour) workplace observations and 48 (2-hour) interview/think-aloud sessions across all eight of the engineer participants who represent several engineering disciplines (i.e., biological, chemical, civil, electrical/computer, environmental, and mechanical) and engineering workplace contexts (global business, local start-up, manufacturing plant, not-for-profit organization). De-identified data is made available for use by other researchers as secondary data as per the project's Data Management Plan.

Leadership and Service Activities

Leadership

Society of Women Engineers, Activities Committee Member, 2019-2020

Utah State University – Logan, UT

Transfer Student Organization, President, 2016

Valparaiso University – Valparaiso, IN

STEM Outreach

Engineering Design Process Outreach, Activity Co-Leader, 2016

Valparaiso University – Valparaiso, IN

Professional Development Activities

Conference, 2020 Annual ASEE Conference & Exposition, June 22-26, 2020; Virtual

Conference, 2019 Annual ASEE Conference & Exposition, June 16-19, 2019; Tampa, FL

Conference, 2019 Annual Meeting of the American Educational Research Association (AERA), April 5-9, 2019; Toronto, Canada

Conference, 2018 Annual ASEE Conference & Exposition, June 24-27, 2018; Salt Lake City, UT

Conference, Rocky Mountain Section ASEE Conference, September 22-23, 2017; Provo, UT

Conference, Fall Interdisciplinary Research Symposium, October 28, 2016; Valparaiso, IN

Exposition, College of Engineering Senior Design Expo, April 30, 2016; Valparaiso, IN

Conference, Celebration of Undergraduate Scholarship, April 23, 2016; Valparaiso, IN

Conference, IL/IN Regional ASEE Conference, April 9, 2016; Quad Cities, IL

Exposition, The Big Ten+ Graduate School Exposition, October 4-5, 2015; West Lafayette, IN

Conference, Annual International SFF Symposium, August 10-12, 2015; Austin, TX

Membership in Professional Societies

Society of Women Engineers

American Society for Engineering Education

Research Interests

K-12 engineering education

Engineering curriculum development

K-12 curriculum development

Diversity and inclusion in engineering

Software and Computer Experience

Canvas

Dedoose

MAXQDA

MATLAB

FEMAP

Solidworks